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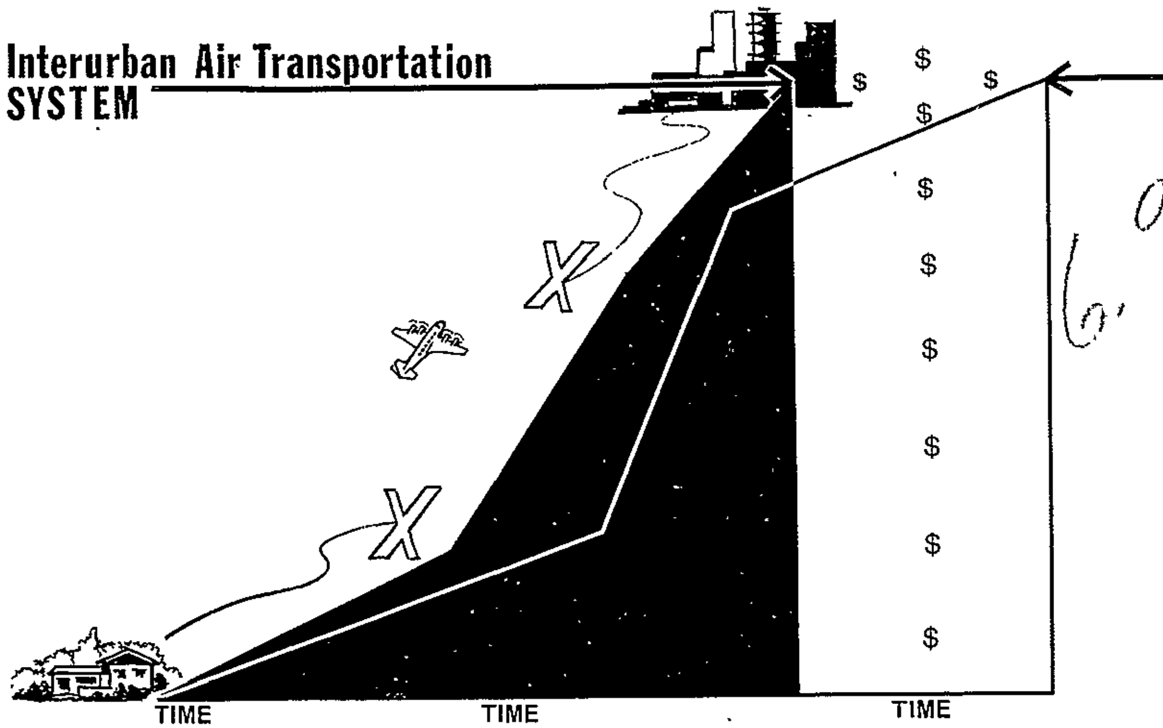

A GRADUATE PROJECT IN COMPLEX SYSTEMS DESIGN

Presented by the Students of AE-EE-ME 655-656 (Winter-Spring Quarters, 1969)

DECEMBER 1969

GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia 30332

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PREFACE

The purpose of this report is to present the results of graduate students' applying the concepts and methodlogy of complex systems design using the air transportation system as a research vehicle. The professor, manager or student desiring a familiarization of the application of the systems approach will find the Summary most useful. If a particular reader has a more detailed interest in the methodology or the approach as applied to the air transportation system, the Chapters of the report should well aquaint him with the necessary material. Finally if highly detailed information is required for further study, research or the like, the Appendices contain the majority of this form of information.

Referenced portions of Chapters and Appendices have a listing of such references at the end of each. For the benefit of any reader who wishes further information on any portions of the report, the responsible author(s) of a particular section is (are) listed in the table of contents. A list of students who participated in the course may be found in Appendix 1-B of this report.

This report owes its completion not only to the students who wrote the individual articles, but also to the faculty advisors who offered technical advice on some of the problem areas encountered. A special thanks is given to the typists Judy Brawdy, Becky Thomas, Judy Richards, Jane Gann and Louise Barge and draftsmen Barry Lyon and Tom Wedincamp without whose talents a quality report could not be assembled.

Credit is due the Lockheed-Georgia Company which offered technical advice which was most benefical to the progress of this study. A word here must also be added in thanks to those lecturers who gave generously

of their time to present the class with background information important to this project. A listing of these speakers may be found in Appendix 1-A.

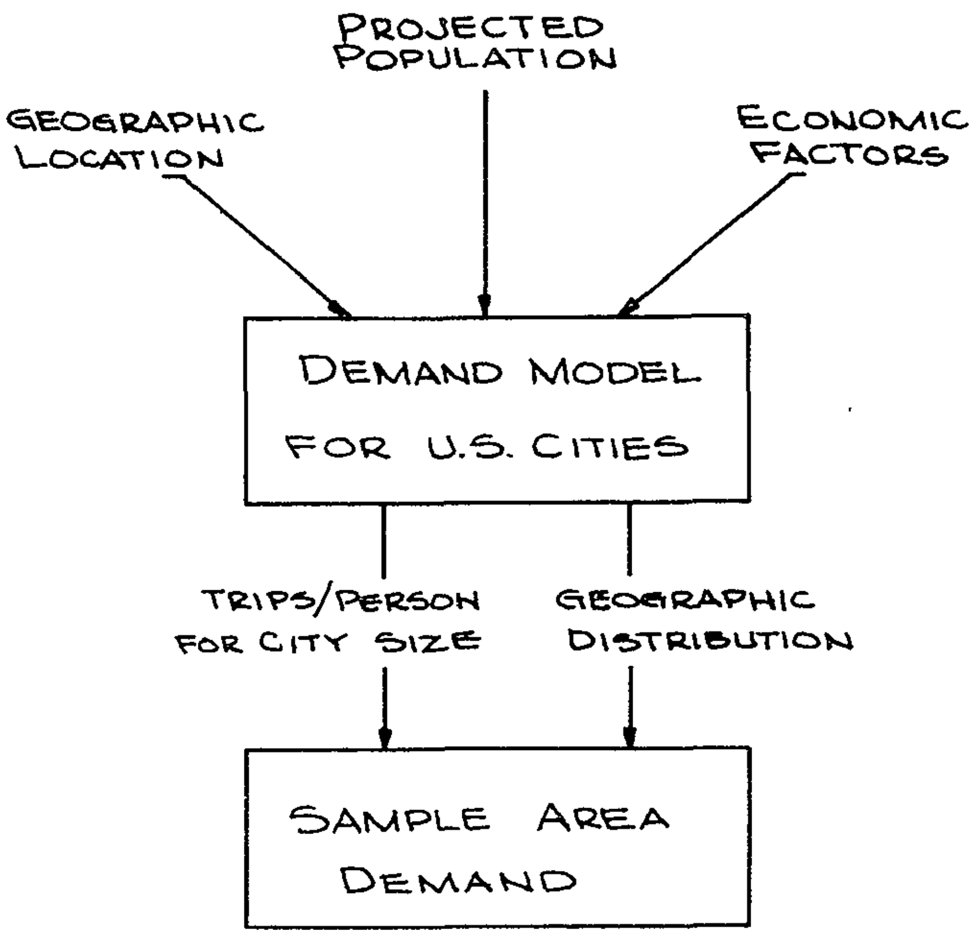
Finally, the class is indebted for material support given by the National Aeronautics and Space Administration, National Science Foundation and the schools of Aerospace, Electrical, Industrial and Systems, and Mechanical Engineering of the Georgia Institute of Technology. The relevant NASA grants are NGT 11-002-064 and NGR 11-002-081. NSF support came from contract number GU 2161, an institutional grant.

SUMMARY

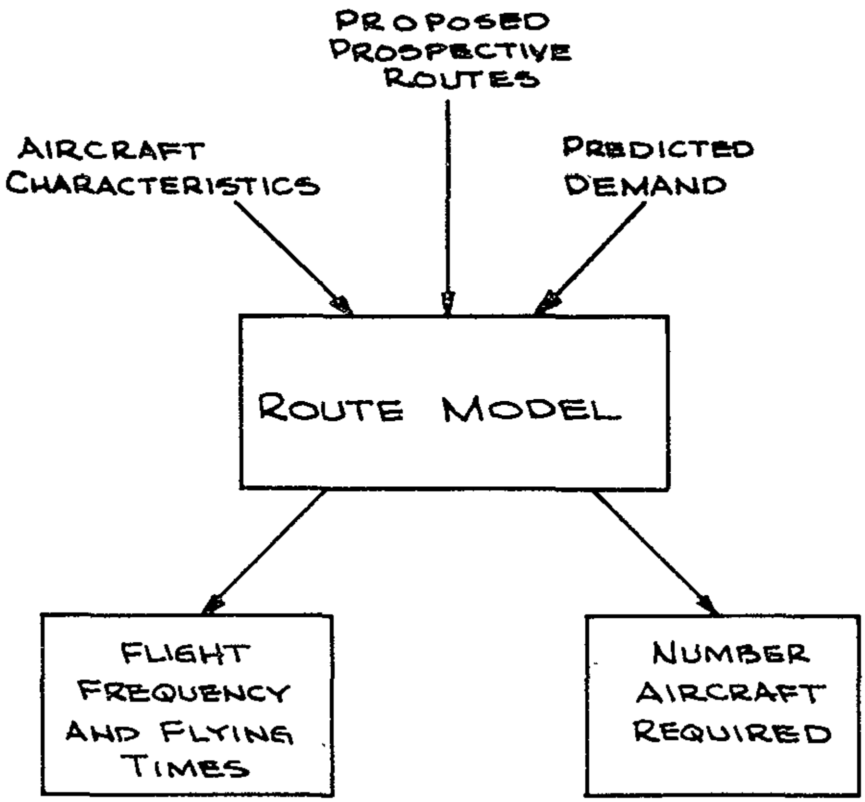
One of the greatest complex problems confronting our society today is the over crowding of the nations air transportation system. The primary cause of the system's congestion is the ever increasing demand for air travel. The major areas of the overall air transportation system need to be altered or even revolutionized in order to satisfy this rising volume of air passengers.

The project assignment for the graduate students enrolled in a six month interdisciplinary course in Complex Systems Design is entitled "a study of interurban public air transportation for the 1975-1985 period." A systems approach was used. The nature of this problem was determined, alternate solutions were posed and measures of effectiveness and cost were applied.

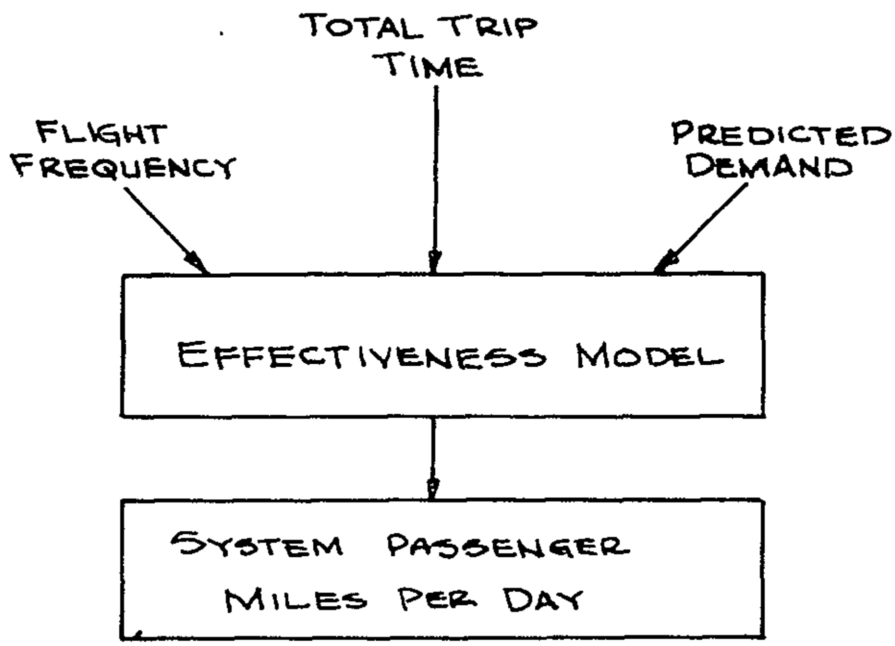
The class was divided into four groups to investigate the basic areas of the system: demand and route structure, air vehicles, terminals and ground facilities, and air traffic control. The Route and Demand group was assigned the tasks of developing route and demand models and determining the measures of effectiveness for the system. The Terminal group studied passenger and baggage handling, terminal interface transportation and airport location and configurations. The Vehicle group was given the tasks of studying existing aircraft design and proposing designs to fulfill the needs of this system. The Air Traffic Control group was responsible for analyzing the effects of congestion on air traffic flow.



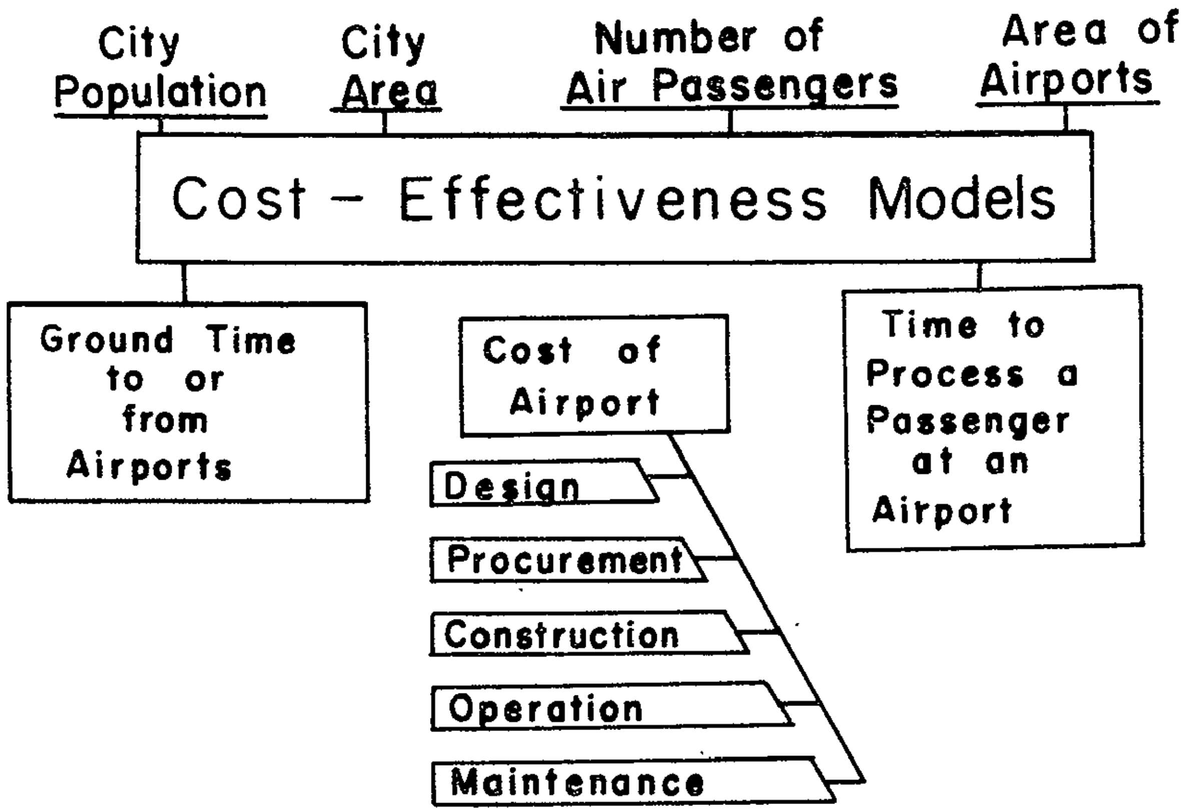
In developing a systems analysis for common carrier air transportation in the United States, three of the most significant aspects involve forecasts for air transportation demand, route selection and assignments of aircraft for the forecast period. After a study of the existing models for air transportation demand the concept of a travel generator model evolved. Such a model generates the demand between two cities based on the populations of the two cities and the distance between them. Certain other characteristics, such as average income of a city, can also be included in the model. Once the demand model was developed, estimates for future travel demand were made for 144 urbanized areas throughout the United States. This data was then reduced to a sample area of eleven cities to comply with restrictions of other models. A comparison of other predictions was made to make adjustments for certain regional considerations.



The function of the route model is to assign aircraft to specific trip patterns to satisfy travel demand. There are three essential groups of input data for this model: forecasted demand for each city pair, a list of possible flight patterns, and aircraft characteristics such as passenger capacity, range and speed. The route model provides outputs which specify the operations per day by aircraft type at each location and the number and flying range of each aircraft type that is necessary to meet the total system demand. The procedure used was simply an assignment of aircraft to the most direct routes whenever possible, using intermediate stops only when demand was not adequate for direct routings.

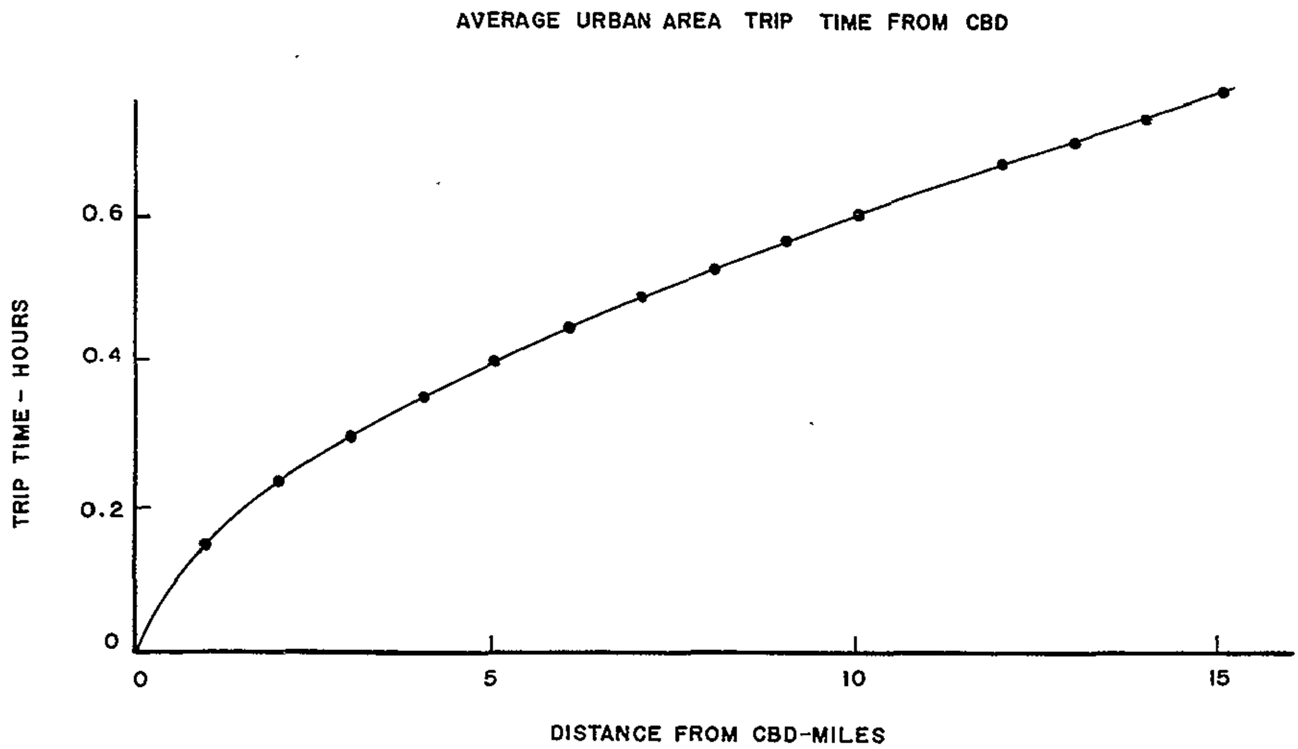


Once the demand has been established and a route configuration determined the effectiveness model was utilized to establish the total passenger miles the system carried. System effectiveness is measured in total passenger miles indicating that measures taken to increase the probability of flying increase the system effectiveness. The model includes factors which are responsive to flight frequency and to total travel time (door-to-door). It was hoped that a sensitivity factor for cost would be included but this has been omitted. Each system tested was forced by the route model to provide service for the projected demand. This level of service was then tested by the effectiveness model to evaluate the actual passenger loads.

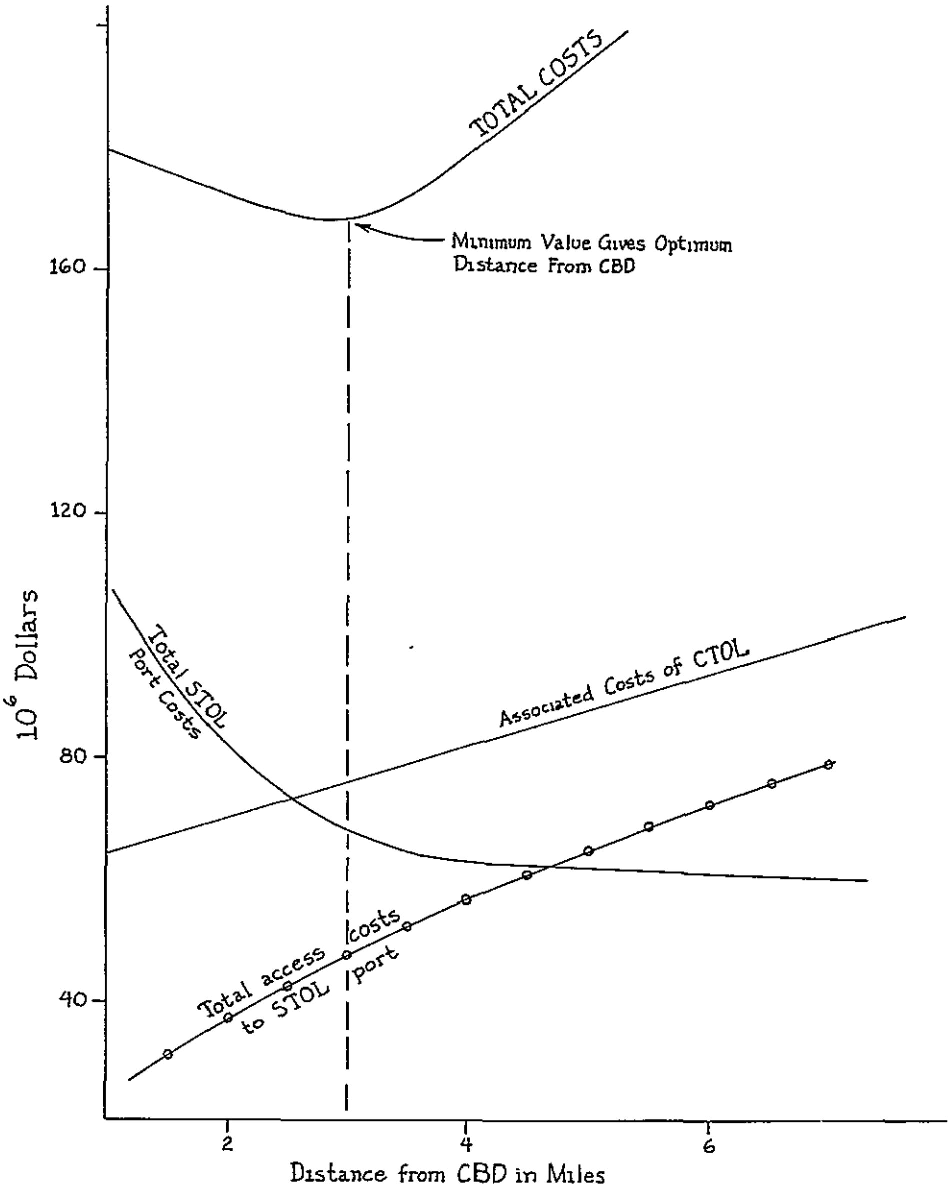


The terminal model, a mathematical representation of the terminal subsystem, is designed to evaluate the cost effectiveness of various alternatives for future airport systems. The primary objectives of the terminal model are to determine ground access time to and from the airport or STOL (Short Take-Off and Landing) port, to determine the total construction, design and operations costs for the cities and aircraft mixes tested, and to estimate the processing time of a passenger at an airport. The secondary objectives of this model are to consider alternate ground transportation modes, various terminal configurations and increased automation of baggage handling.

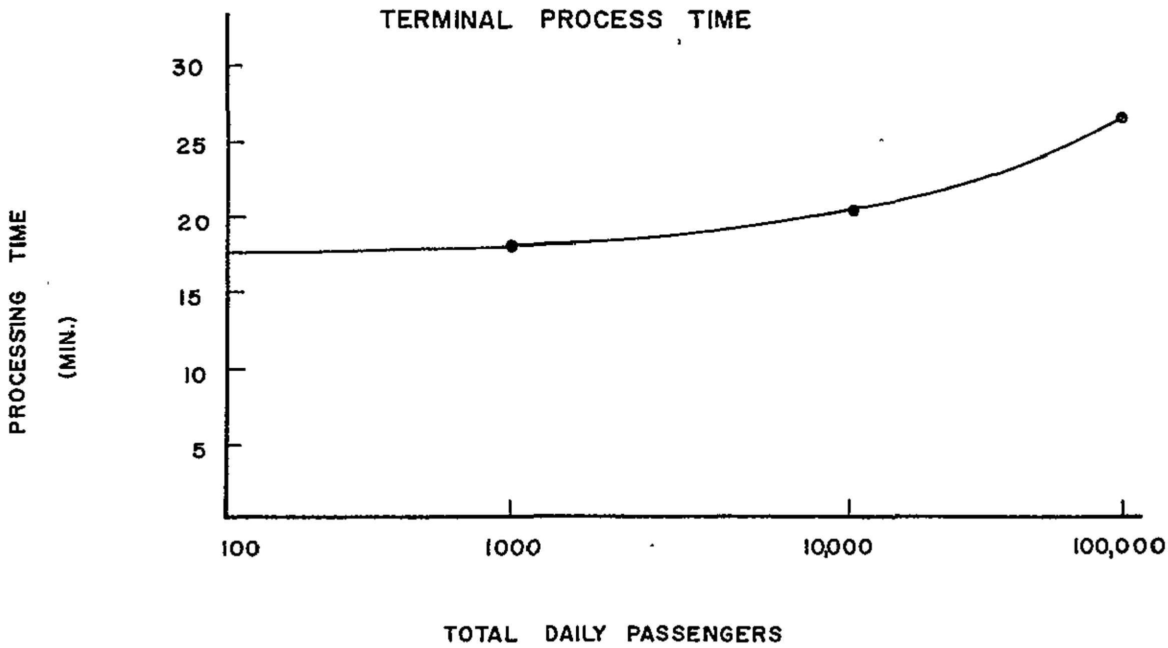
The costs considered were land, terminal buildings, terminal area, ground access time, terminal operations and maintenance. The model determines costs as functions of port location within an urban area, number of passengers, runway configuration and total airport area.



A major contributing factor in the development of the terminal model is the location of the STOL port within an urban area. The STOL port model basically optimizes on the basis of location related costs for the 1975-1985 time frame. To develop this model, the average urban area trip time from the central business district is used as the ground access time for both the airport and STOL port. The trip time is multiplied by the expected mean value of time (dollars per hour) of the average air traveler for the period tested. The result is the expected air traveler's value of time while in the ground transportation mode of the air trip. This is then multiplied by the predicted total number of passengers utilizing the STOL port for the design period. This yields the STOL passengers' total value of time involved with ground transportation access to the airport or STOL port.



The total STOL port procurement and operating costs for the 1975-1985 period are based on estimated construction and operating costs and predicted urban land values. The summation of these costs, the total ground transportation access costs (passenger's total value of time) and the conventional take-off landing (CTOL) airport related costs yield the total terminal costs. The minimum total terminal cost establishes the distance from the central business district (CBD) at which the STOL port location would be optional.



Another element of the terminal model is the process time submodel. The four major parameters of the model are:

1. Time consumed by a passenger moving from an automobile in the parking lot or from some public conveyance to the terminal check-in point.
2. Time for ticketing, baggage check-in or baggage claim.
3. Passenger transit time to the correct gate position.
4. Time needed for aircraft boarding.

Boarding time is considered constant using an average boarding time for aircraft tested. Baggage check-in and ticket clearance time values are known airline threshold times. Baggage claim time is determined by the proposed baggage handling system described in this report. Functional relationships are used for movement time from a parked automobile (or public conveyance) to the terminal and transit time from the check-in point to the gate position.

GROUND TRANSPORTATION MODES

A number of ground transportation systems are considered for passenger transit to and from the terminal. They include conventional rapid rail, busways, small buses and automobiles. Additionally several other variations were proposed but were not pursued further for lack of information and time. The evaluation of modes must consider benefits due to decreased access time versus the additional terminal cost due to improved ground transportation.

BAGGAGE HANDLING SYSTEM

The baggage handling system is one which must be automated in order to handle the demand of the 1980's in large cities. An automated baggage system may also reduce passenger delays. Since no fully automatic system exists today it was necessary to design one. The designed system is modular in concept so that it may be used at terminals of various size. A cost model of this system was developed in order to make cost-effective decisions as to the degree of automation to be used.

AIRPORT CONFIGURATIONS

Three basic terminal units are considered and parametrically studied: Satellite, Finger and Open Apron. Each is a complete unit in itself and can handle a typical peak hour load of 3600 passengers. Parametric cost equations were developed for each type of terminal subdivision (parking, baggage, handling, etc.).

SATELLITE TERMINAL AND FINGER TERMINAL I

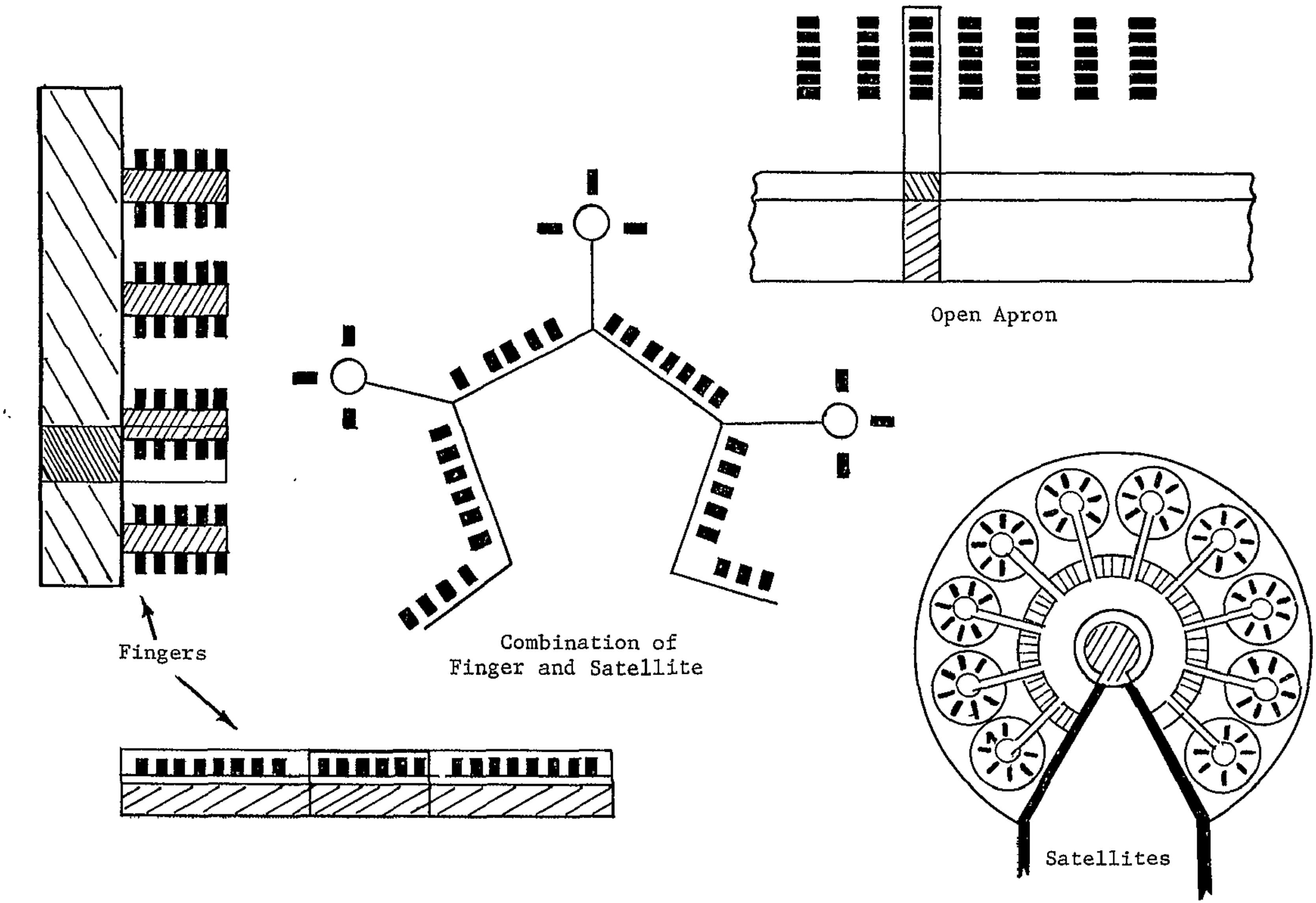
Each gate position can be reached by intra city transport.

FINGER TERMINAL II

This configuration allows the terminal to be built along runways.

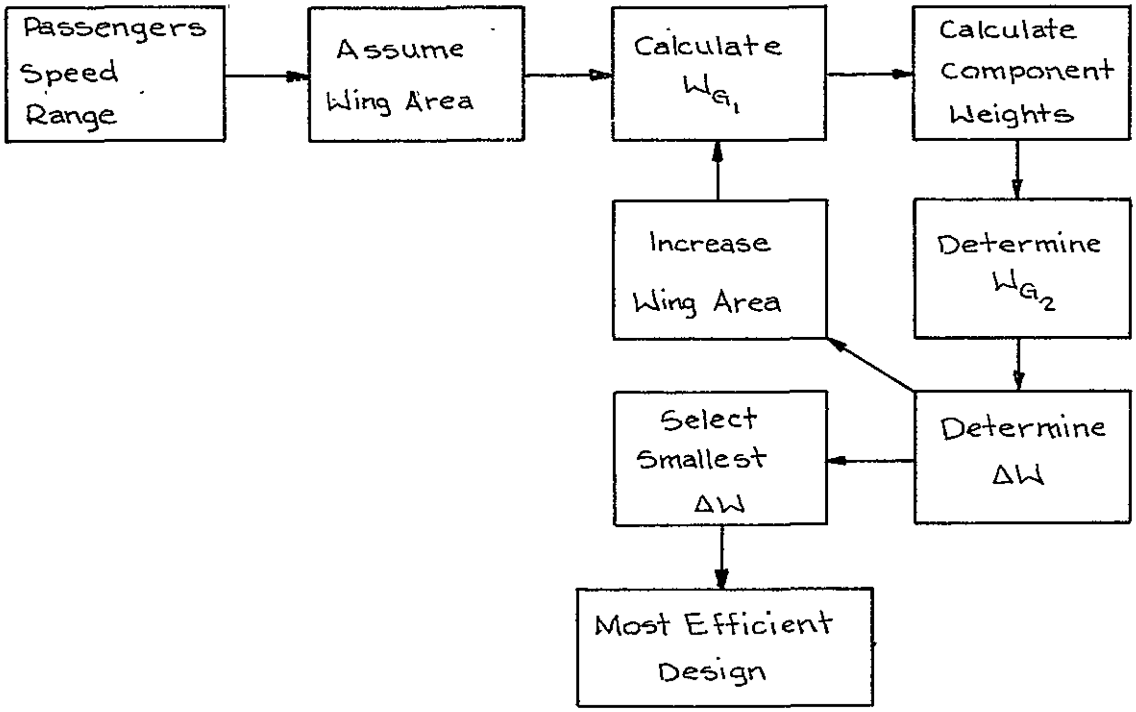
OPEN APRON

Aircraft require no external vehicular assistance. A subway transports passengers between the aircraft and terminal.



Open Apron
Combination of
Finger and Satellite
Fingers
Satellites

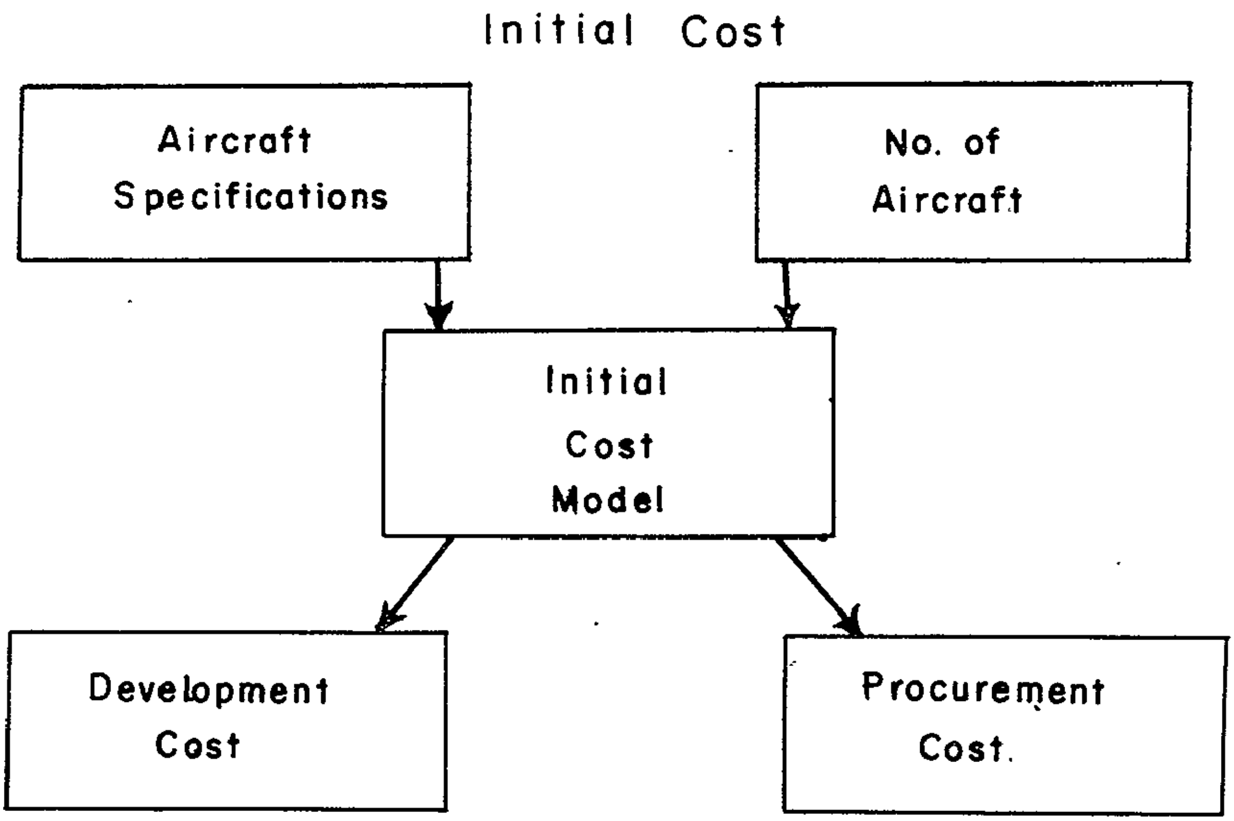
DESIGN MODEL



Through the development of mathematical models, a variety of fixed wing STOL turbo prop aircraft designs were provided for integration into a projected commercial air fleet of the 1980's. The procedure employed in the air vehicle design model, was one of iteration of aircraft gross weight by variation of wing area to meet selected performance specifications. An initial gross weight was computed based on a given passenger load, cruise speed, range and a selected minimal wing area. A second gross weight was then computed based on this initial gross weight and a more detailed summation of component weights required to meet the specific performance criteria. Through an iteration procedure, wing area was increased incrementally, resulting in new calculations of initial gross weights was computed during each loop of the process. The selected design for each set of performance criteria was that corresponding to the smallest difference in first and second gross weights.

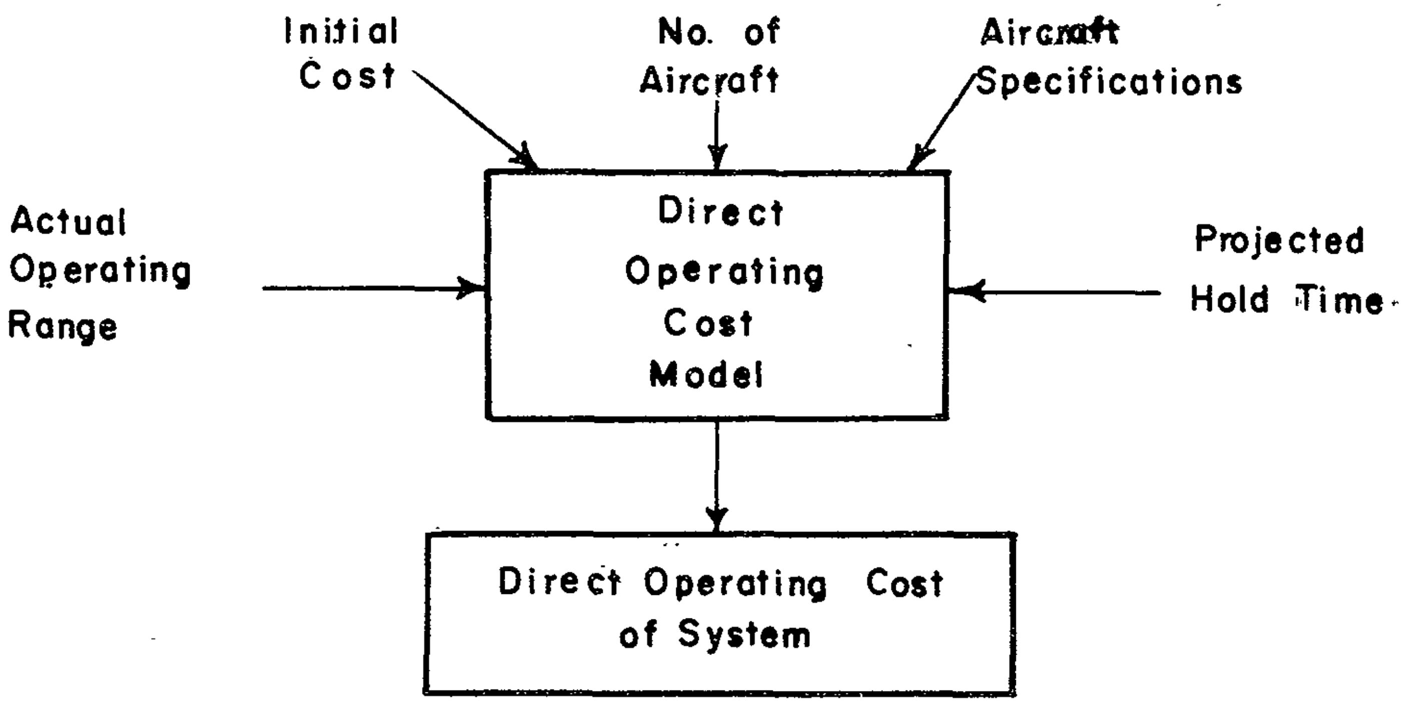
Interior design of each aircraft configuration was selected from various arrangements of passenger seating ranging from four passengers abreast to seven abreast. Fuselage length and fuselage width were calculated based on these seating arrangements in addition to allowances for passenger doors and lavatories. Buffets and cloakroom space could be included in interior accomodations with a slight penalty in passenger capacity.

Two mathematical models were developed to provide aircraft cost analysis. These cost models provided input to the overall system cost analysis.



Initial cost, consisting of development and procurement costs for each design configuration, were provided through the use of formulae based on aircraft characteristics and number of aircraft projected for production.

Direct Operating Cost



Direct operating cost, consisting of direct maintenance and flight operation costs, was provided through the use of formulae based on aircraft characteristics, planned operating range and size of aircraft fleet.

Today's air traffic control system is not operating smoothly and efficiently. In simple terms, aircraft are flying faster and faster to longer and longer waiting lines. This problem has become increasingly more evident in the past 12 months.

PROBLEM: Flight delays in the present air traffic control system are excessive and in some cases prohibitive.

A study of the problem found that the major delays occurred in the terminal area. It was determined that reduction of these delays below some acceptable limit would satisfactorily alleviate the problem. The design objectives of the air traffic control group were determined to be:

1. Design of an air traffic control system capable of accepting air traffic loads of the 1975-85 time period.
2. Design of an air traffic control system such that delay will be less than the acceptable limit.
3. Design of a system that is capable of being tailored to any given HUB (a HUB is a flight terminal area).

After careful consideration, it was decided that the most practical and useful approach would be to use the digital computer to simulate the terminal air traffic control area. A fixed runway configuration was assumed and the input parameters were varied to establish the resulting delay in seconds for the fixed configuration. This delay was established with model inputs of demand, aircraft mix, and five critical aircraft separation prameters. One model input, demand, which was measured in operations per hour, was system capacity when a particular delay criteria was specified. Additonally, excess delay was determined to be the result of congestion, inadequate procedures and management, and inadequate equipment and facilities.

CAPACITY

- Airspace
- NAVAIDS
- Training
- DELAY
- Weather

SAFELY $\geq$ $\boxed{\text{DEMAND}}$

- Growth
- Aircraft Mix
- Aircraft Performance

An air traffic control system should be capable of providing adequate capacity. This capacity is predicated on delay criteria and the actual system demand. Demand and capacity are both functions of the indicated considerations.

IMPROVEMENT TECHNIQUES

PREASSIGNED DEPARTURE/ARRIVAL TIME

SPEED CLASS SEQUENCING

PATH STRETCHING

COMPUTER-AIDED APPROACH SEQUENCING

▲ SEPARATION REDUCTION

Five basic techniques to improve the air traffic control system have been identified. The technique considered in this analysis was separation reduction. This technique offers significant opportunities for reduction in delays.

Although many combinations of equipment are possible, three basic packages were considered in this study:

PACKAGE 1	PACKAGE 2	PACKAGE 3
ASR-4 Radar	ARS-7 Radar	Area Navigation Equipment
ILS Ground Equipment	NAS "A" Equipment	PVOR/DME altimeter
VOR/DME Stations	ILS Ground Equipment	AILS Ground Equipment
VOR/DME Receivers	VOR/DME Stations	Coder Transponder
Altimeters	Altimeters	ARS-7 Radar
ILS Aircraft Equipment	ILS Aircraft Equipment	NAS "A" Equipment
Transponder	Coder Transponders	AILS Air Equipment
	VOR/DME Receivers	VOR/DME

Package 1 corresponds to the present air traffic control system.

Each package was compared to the others by parameters of time (T,F,R,C AND A).

These times were based on equipment accuracy in indicating aircraft location and on the probability of an aircraft being in a specified area configured around the indicated point.

T - Departure followed by departure time (take off to take off time) for two aircraft.

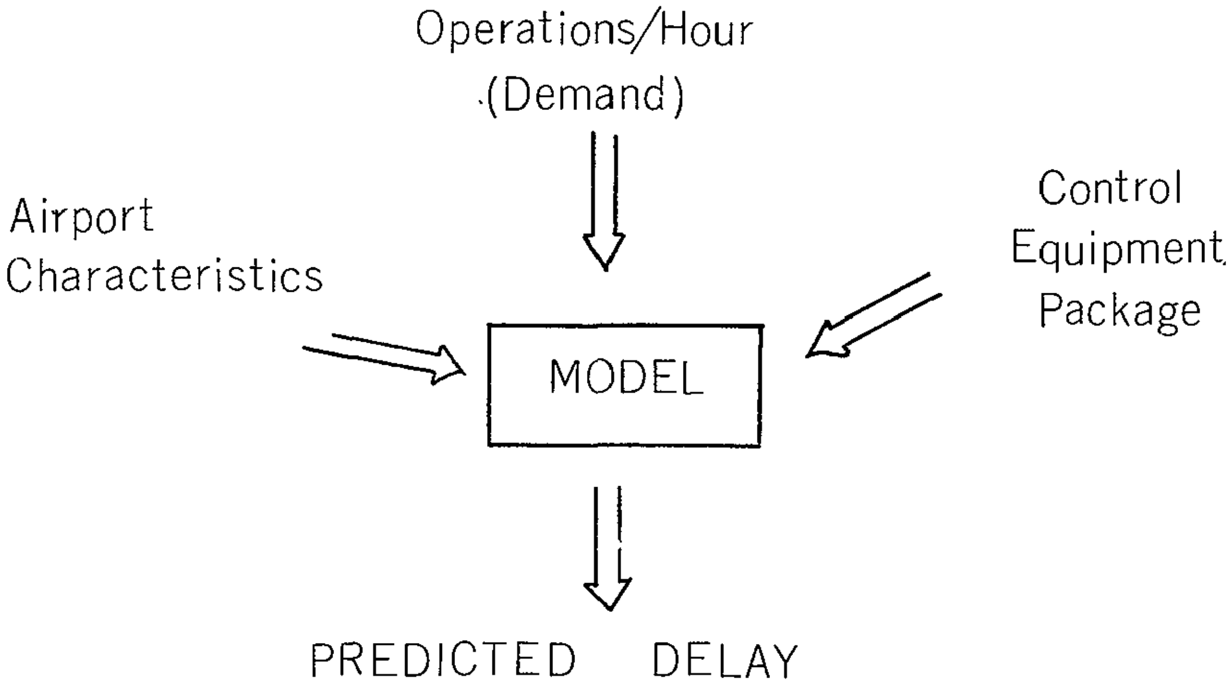
F - Departure followed by arrival time.

R - Runway occupancy time for each aircraft.

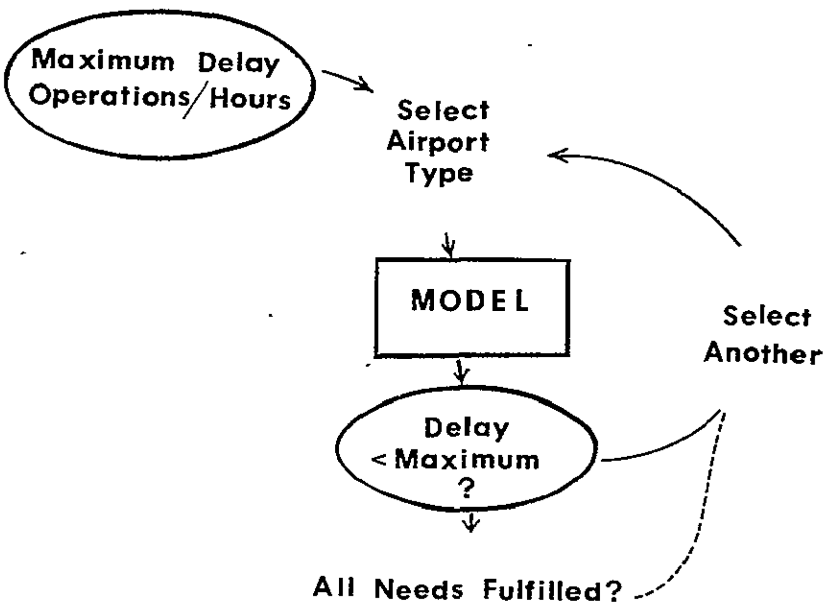
C - Time from commitment to land (must touch ground) to over threshold (end of runway).

A - Arrival followed by arrival time.

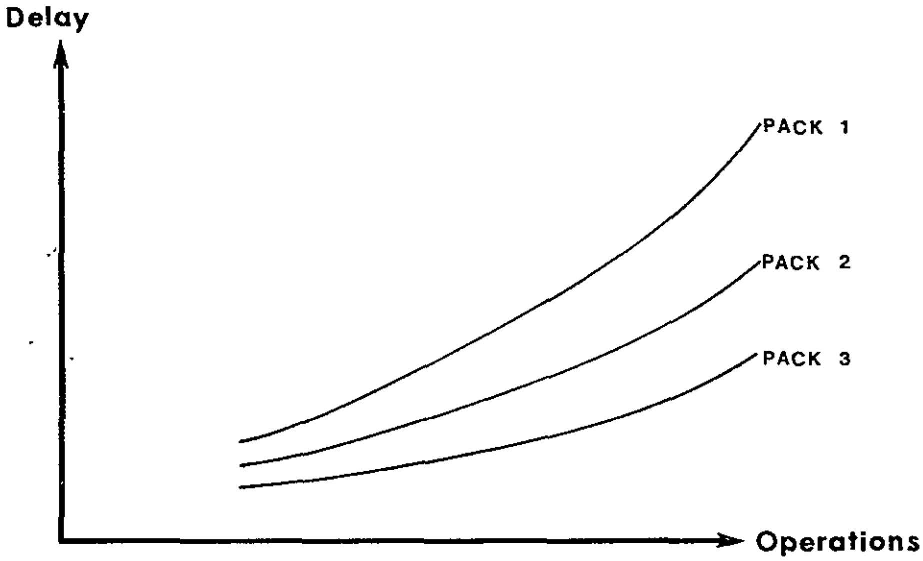
PARAMETER	PACKAGES 1	2	3
C (seconds)	28	24.4	24.4
T (seconds)	90	40.5	40.5
F (seconds)	65	57.8	57.8
R (seconds)	52	46.6	46.6



The computer model used in the control systems analysis had two functions. The first was to determine delay for each package for varying demand.

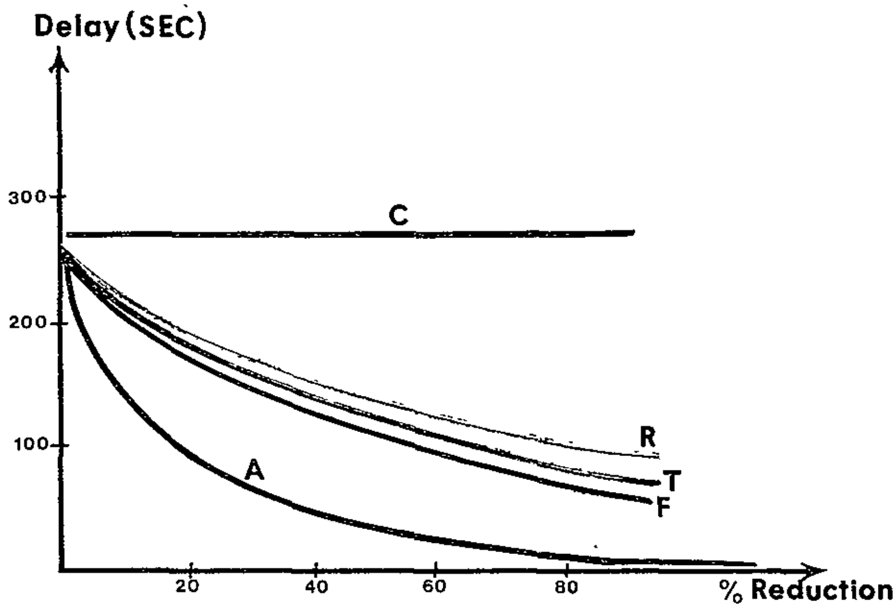


The second function was selection of airport configuration most suitable for each HUB.



MIX vs. DELAY

For a given number of operations per hour control packages 2 and 3 offer substantially decreased delay by allowing reduced separations.



T, F, R, C and A AFFECT DELAY

The greatest benefits may be derived from substitution/innovation of equipment or facilities that will improve the time factor A.

ADDITIONAL CONTROL SYSTEM CONCLUSIONS

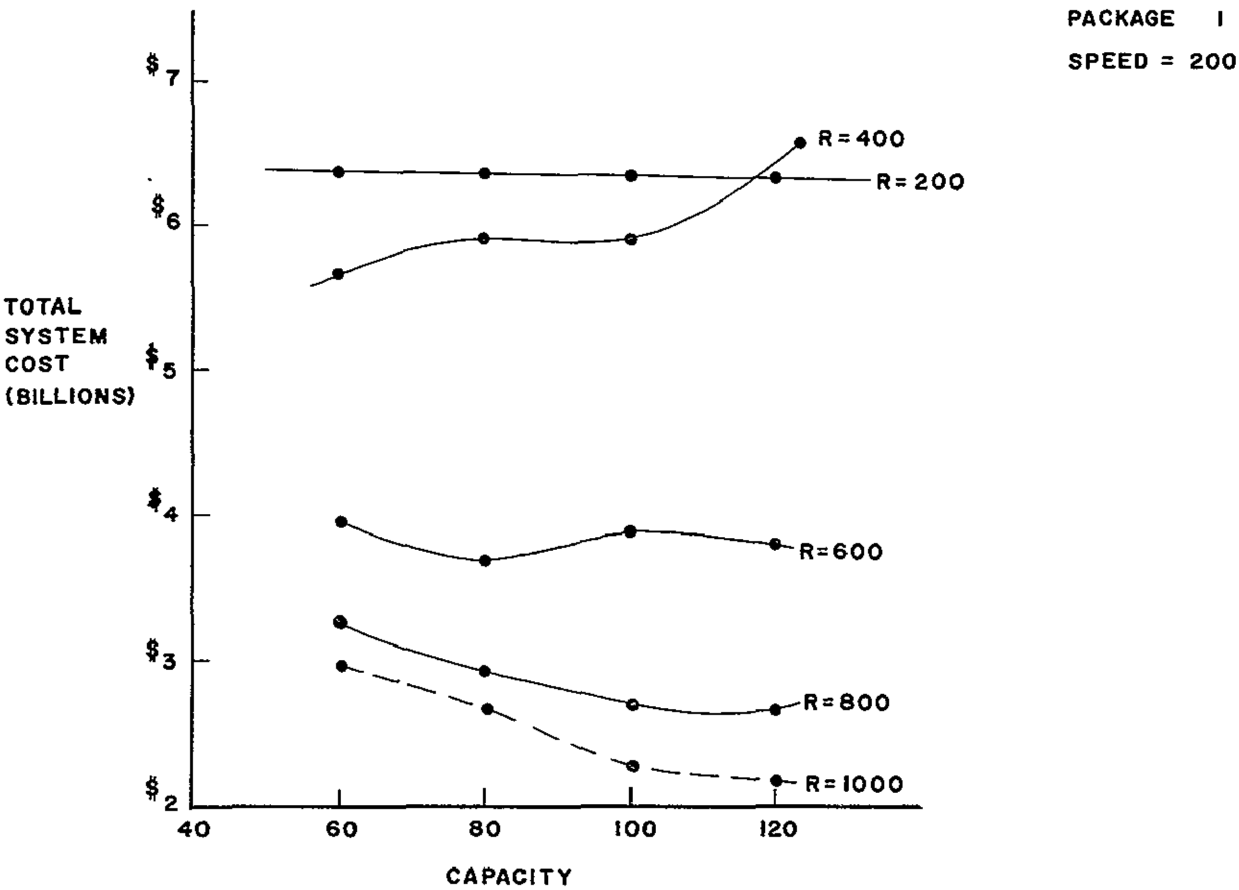
- The STOL aircraft, as expected, performs more satisfactorily when it is scheduled for operations into and out of a 100% STOL airport.
- The introduction of added runways for use by general aviation reduces delay. This results from the elimination of slower aircraft in the general area waiting to land.
- The introduction of an advanced ILS system will substantially increase the level of safety for air traffic.
- Benefit may be derived from development of related equipment. Items of equipment such as fog dispersal devices, runway heating systems, aircraft deicers are of this "related equipment" category. This effort will contribute to decreased "surges" in the ATC system.

ANALYSIS OF RESULTS AND CONCLUSIONS

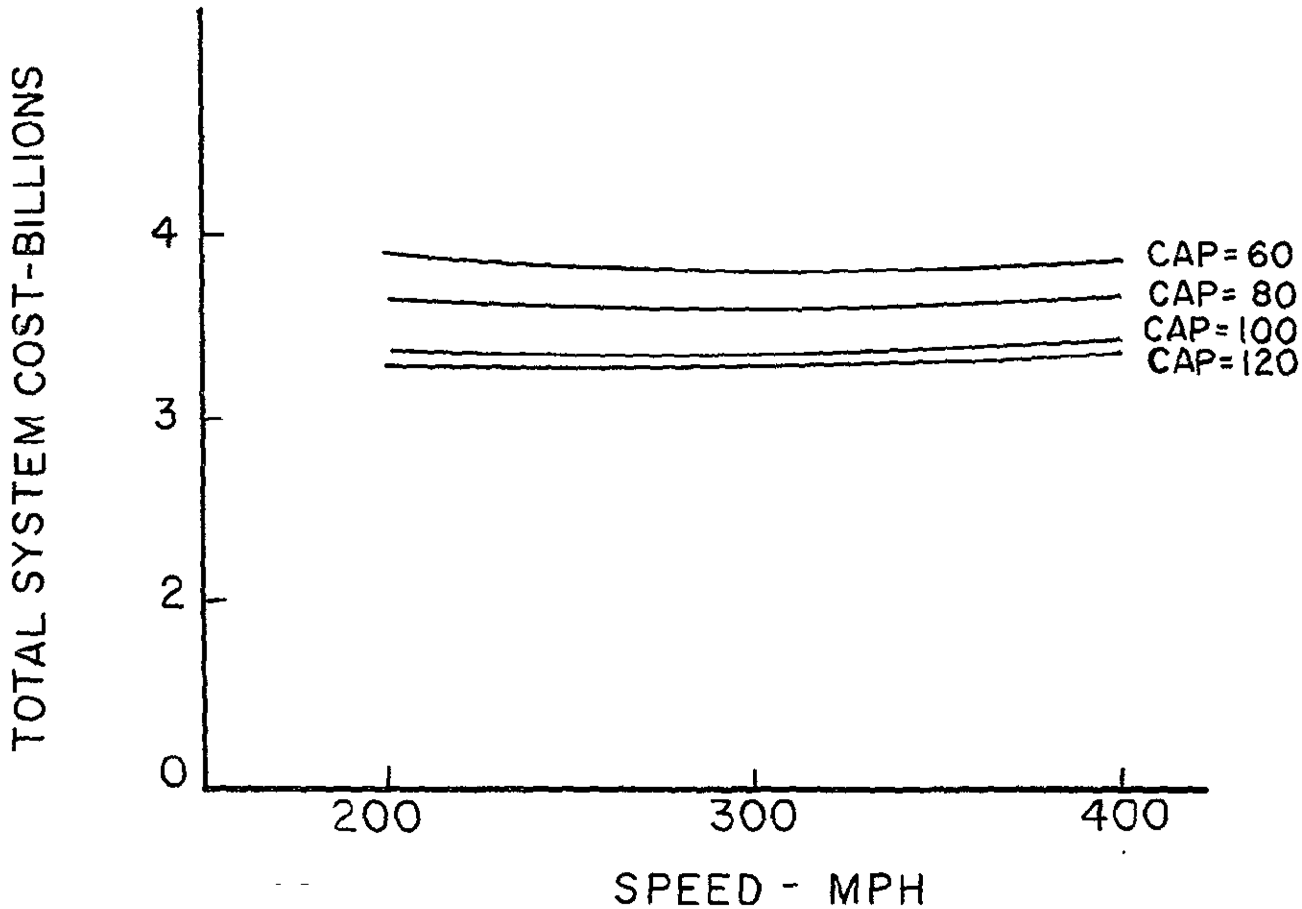
One computer run involving 189 alternative solutions was made to investigate the effects of four variables on the system. They were:

1. Aircraft Design Range (STOL)
2. Aircraft Cruise Speed (STOL)
3. Aircraft Passenger Capacity (STOL)
4. Air Traffic Control Package

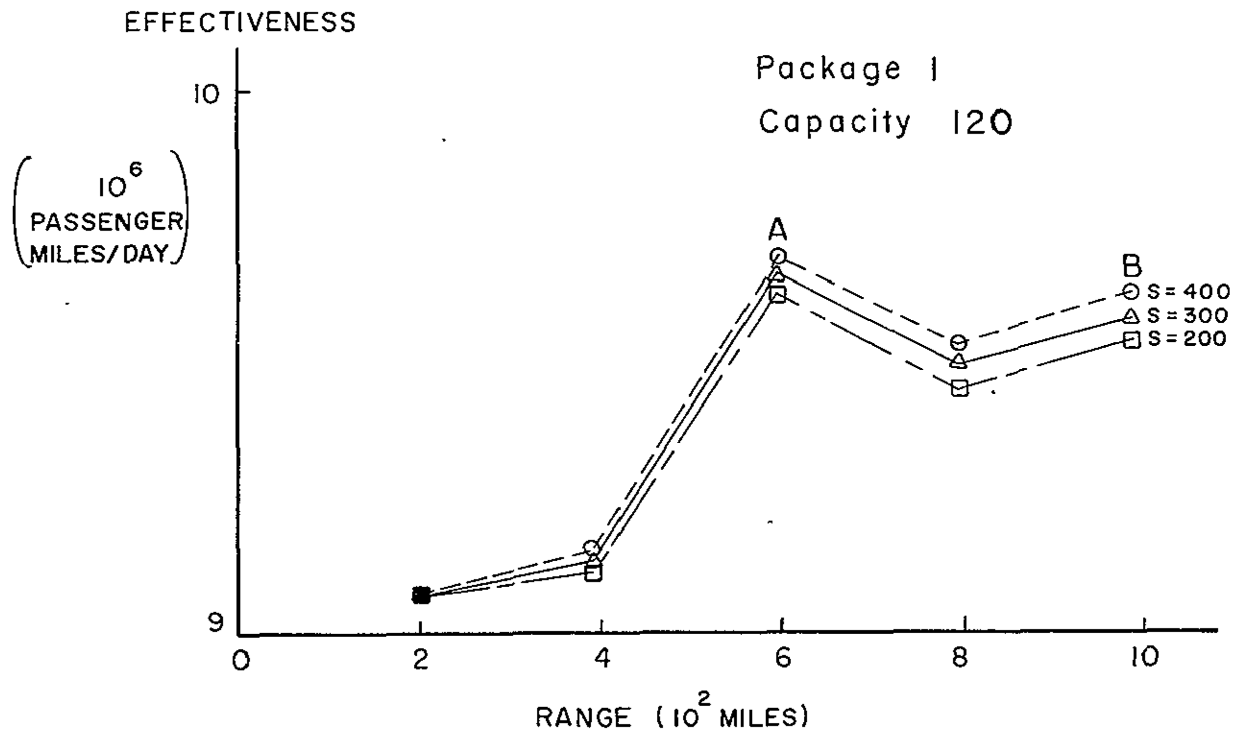
Two dependent variables, the system cost and system effectiveness were used in making the final design decision. Data from the computer output was compared graphically in determining the most cost-effective solution. The system chosen incorporated the Lockheed L-1011 Jumbo Jet and a 1000 mile design range, 120 passenger capacity, 400 MPH STOL aircraft. Terminals were designed to fill the needs of the aircraft mix flown to a given city and the present air traffic control system was chosen as being most cost-effective.



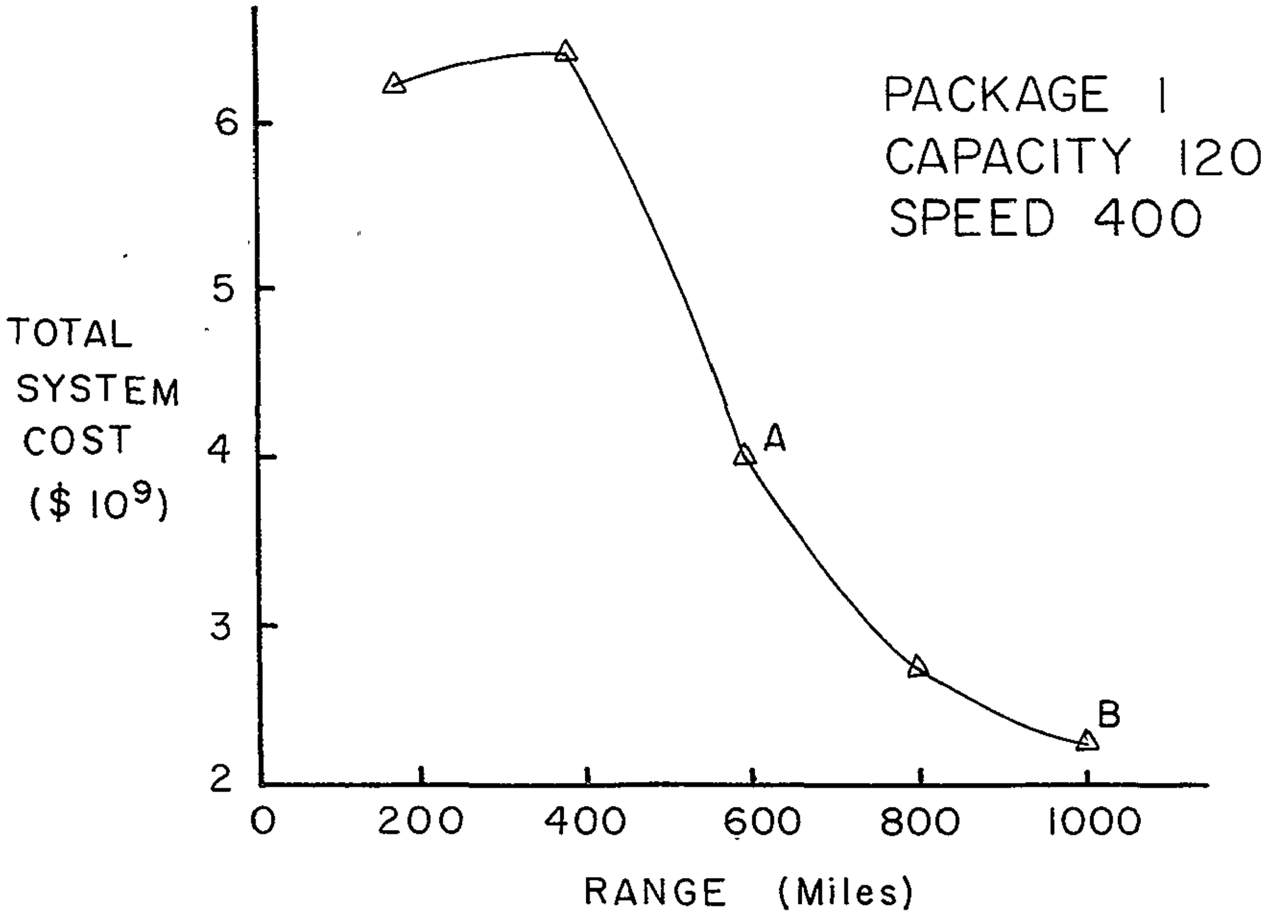
Total System Cost is the sum of the direct operating costs and capital recovery for the aircraft, air traffic control system and terminals for the 1975-1985 period, expanded at six percent interest to the compound amount in 1985. Included are developmental and design costs for new technology and the cost of passengers' time. Approximately fifty graphical plots were used to graphically record data accumulated. Here a plot of total system cost versus passenger capacity for various range aircraft is shown with the air traffic control package and cruise speed being held constant. In other plots the cruise speed was allowed to vary with some other parameter fixed.



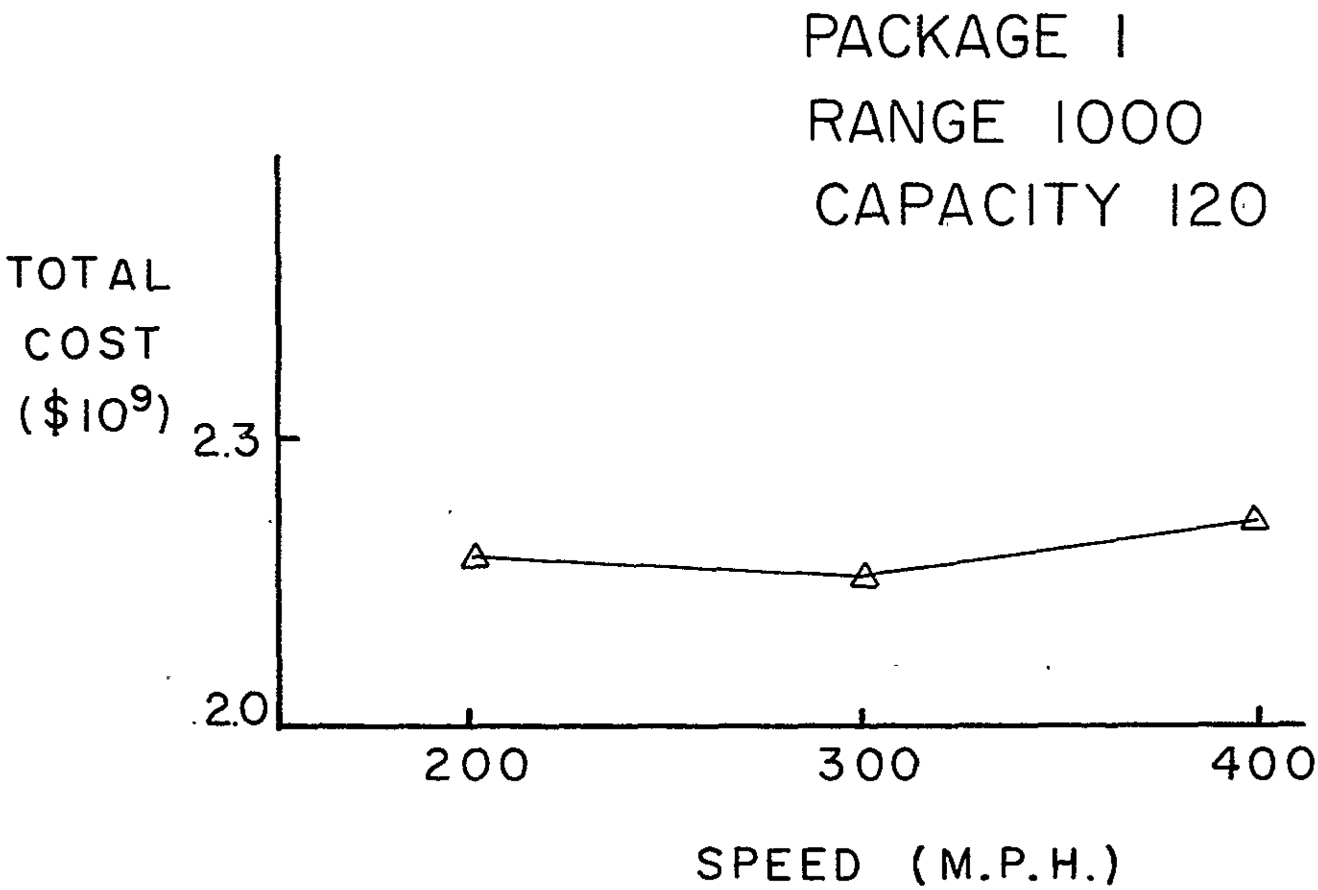
Analysis of the data graphically plotted was instrumental in making final decisions. The total system cost was found to be lowest for the larger 120 passenger STOL aircraft. It was also most effective.



In the graph of system effectiveness versus STOL aircraft design range, utilizing control package one and the 120 passenger capacity the ordinate varies from 9 to 10 million passenger miles per day. The total variation in effectiveness is only about five percent. Points A and B, representing 600 and 1000 mile design range aircraft respectively are almost equally effective.

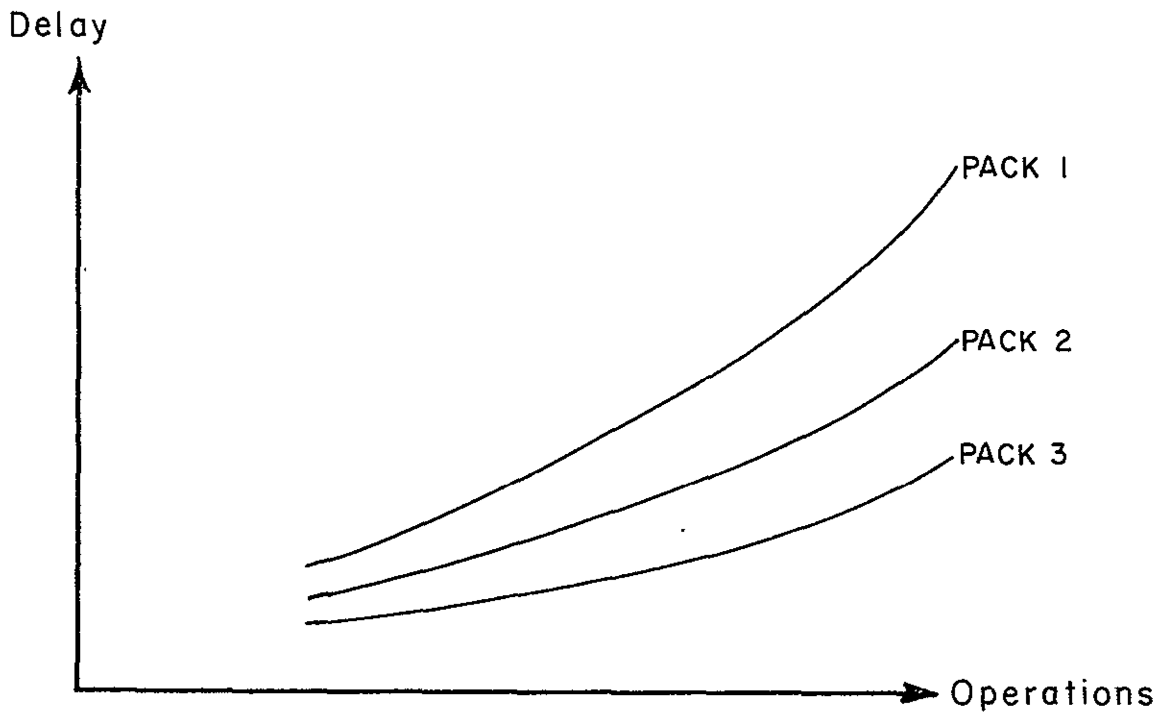


A plot of total system cost versus aircraft design range indicated that the system incorporating the 600 mile range aircraft is at a cost roughly twice as much as the one incorporating the 1000 mile design range aircraft (point B).



The variance in the total system cost with aircraft design speed is also minimized for the 1000 mile design range aircraft. Because of the small variation in system cost and effectiveness with aircraft cruise speed, the faster 400 mph STOL aircraft was chosen for the system. It was also determined that package one, the present day Air Traffic Control System was no less effective than the other two considered and was less costly.

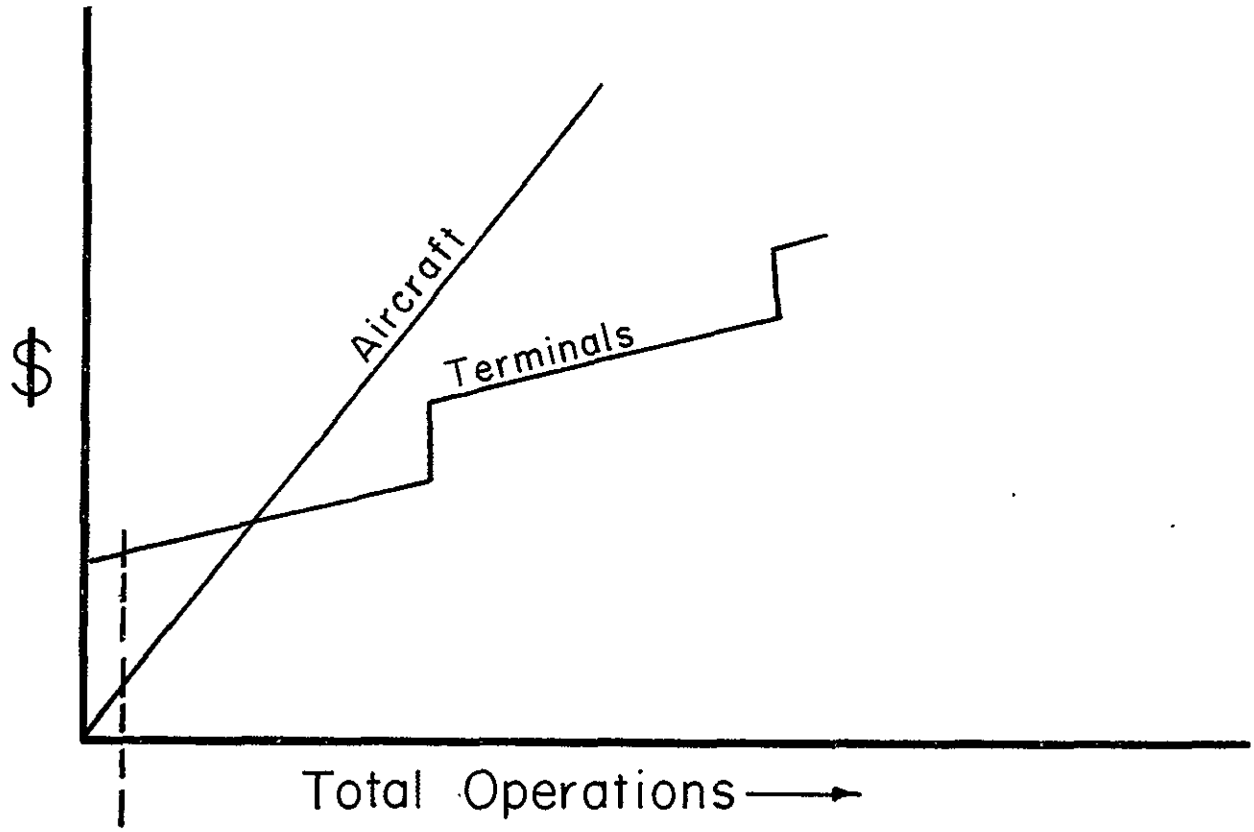
Some of the indicated results are rather unexpected. It is known, for instance, that the present air traffic control system is inadequate even today. It must be remembered that these results are based on a single computer run, in fact, the first run ever made with all the models functioning together.



MIX vs. DELAY

The air traffic control system might also have changed had the demand been higher. The plot of delay versus number of operations shows very little difference in delay for the three control packages when the number of operations is low. There is, however, a considerable difference in delay for the three packages when the number of operations is high. The air traffic control design would most likely have been different had congestion been generated.

In the system using short range STOL aircraft the terminal costs greatly exceeded the aircraft costs, while aircraft costs were slightly greater than terminal costs where long range STOL were in the system.



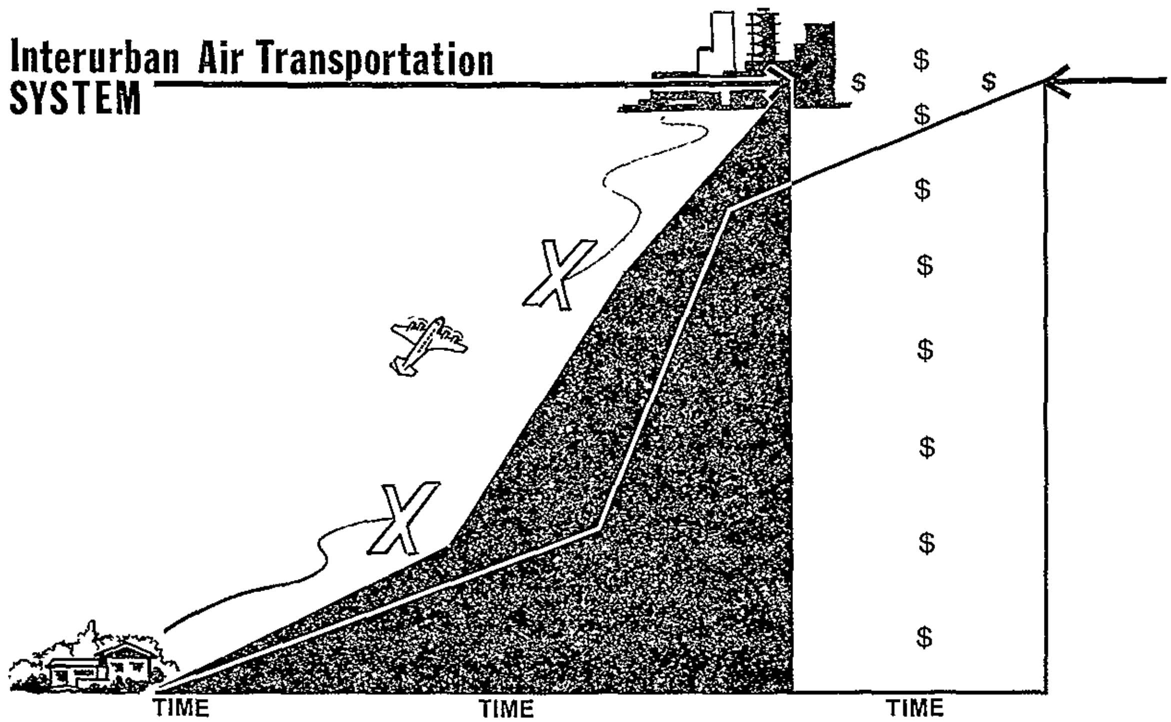
By looking at the effect of Demand on System Cost when the total number of operations is low, the fixed costs of the terminals are predominate. This effect was amplified when short range STOL were in the system, requiring many more of the expensive CTOL terminals than the long range STOL system requires. The effect was further exaggerated by the fact that the CTOL model was written for the moderate to high demand of larger cities. Its fixed cost therefore include a tower, hangers, fire fighting equipment and the like rather than the runway and wind sock required by a very low number of daily operations. The STOL port in contrast has a relatively low fixed cost.

REFINEMENTS

- ALLOW TRANSFERS
- IMPROVE ROUTE ASSIGNMENTS
- PROVIDE FOR INTERNATIONAL AND GENERAL AVIATION
- ANALYZE CURRENT SYSTEMS

It was determined that the simulation would have been more realistic had more air traffic been generated. Several refinements which could have been made on the models would have increased the traffic and perhaps altered some of the final decisions. The transfer of passengers between flights should be considered and route assignments should be based on both aircraft range and capacity. The additional operations imposed on terminals as a result of general aviation and international flight should be taken into account. Finally the current system should be analyzed to provide a reference for comparison with a STOL system.

Interurban Air Transportation SYSTEM



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CHAPTER 1

INTRODUCTION

1.1 General

This report on the Interurban Air Transportation System is the final product of a six month graduate project in Complex Systems Design conducted by students of the Georgia Institute of Technology.

Courses in Complex Systems Design have been offered jointly by the Schools of Aerospace, Electrical and Mechanical Engineering at the Georgia Institute of Technology since 1967. The first course was initiated under the leadership of Drs. Stephen L. Dickerson - School of Mechanical Engineering, C. Virgil Smith - School of Aerospace Engineering, and Thomas M. White - School of Electrical Engineering. This year Professors Gary W. Draper - School of Industrial and Systems Engineering, and Donald W. Dutton - School of Aerospace Engineering joined with the originating faculty in guiding the class.

The design project had two primary objectives. The first objective was to develop in the students an understanding of the systems approach to design and to provide an exercise in its application. The second objective was to obtain meaningful results which could provide useful inputs to future studies.

Throughout the investigation and design, emphasis was placed on a realistic approach to the problem. Only that technology which could reasonably be expected to exist in 1975 was incorporated in the design. It is in this respect that the Georgia Tech Complex Systems Design Program differs most from those of other engineering schools.

1.2 Class Organization

In order to quickly aquaint the students with the problem at hand a series of seven seminars on pertinent topics was presented to the class by authorities in the field. Appendix 1-A contains a list of the speakers and their topics.

During the initial two weeks of the project, the class, initially composed of twenty-five graduate students representing the fields of Aerospace, Industrial, Civil, Electrical and Mechanical Engineering and City Planning, was divided into two or three man teams for "brain storming." Each team developed what it felt to be the ideal interurban air transportation system.

During the brainstorming period it became obvious that no two students observed the same difficulties in air transportation or invisaged the same design solution. The class therefore made the following "official" problem statement:

> "The problem is to design a transportation system to move people and their baggage by air between major cities in the continental United States in the 1975-1985 period."

In order to limit the scope of the problem, the general assumptions given in figure 1.1 were made.

ASSUMPTIONS

- o High speed ground transportation was not considered because of limited time of study.
- o Of STOL (Short Takeoff and Landing) aircraft, only turboprop STOL was considered.
- o Time frame considered was 1975-1985.
- o Mixed fleet of STOL and Lockheed L-1011 was considered as representative.
- o Passenger time has a monetary value.

Figure 1.1

In order to insure close study of every phase of the problem, the class organized itself into four operational groups.

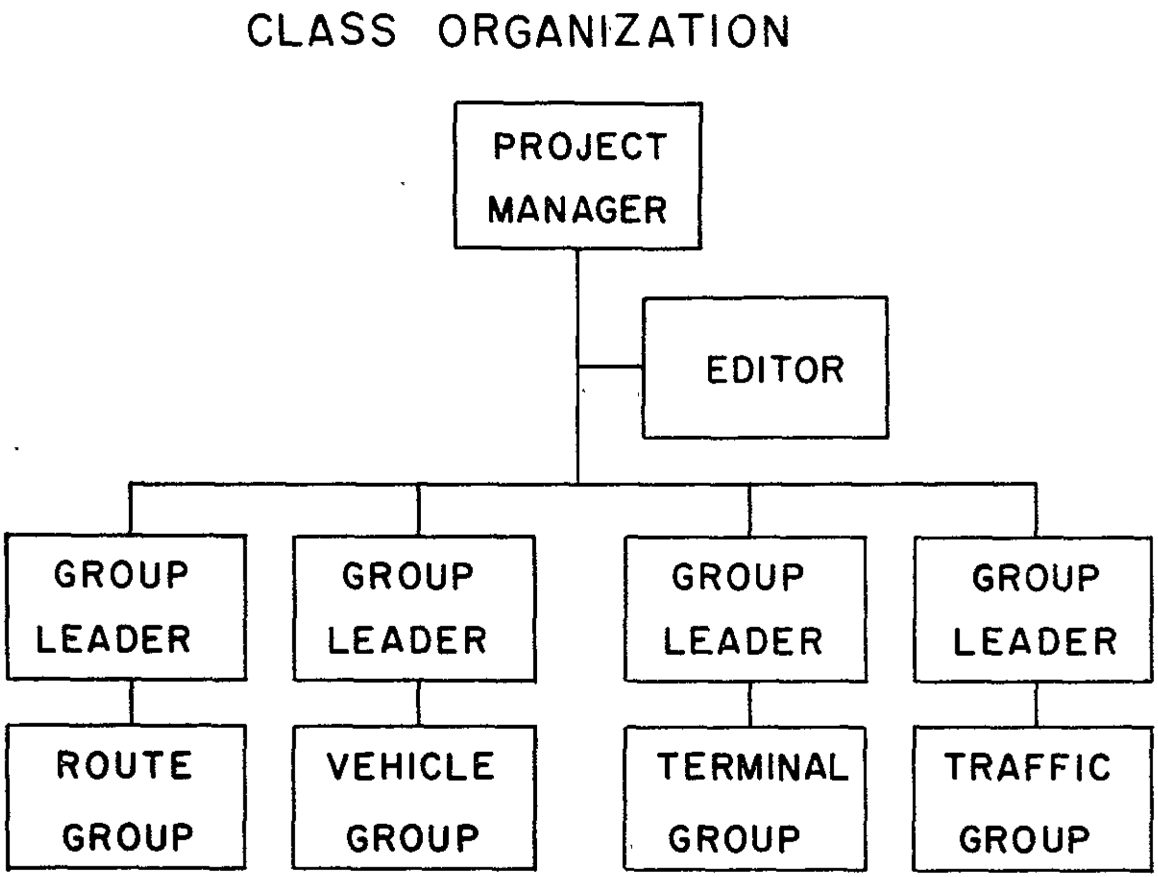


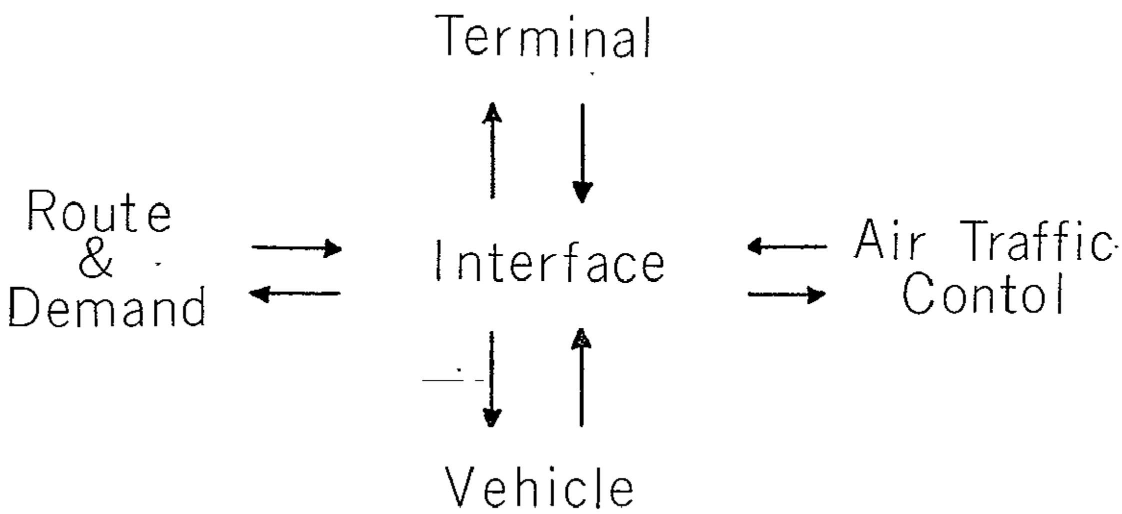
Figure 1.2

Each group was to study one of the major components of the air transportation system: demand and routes, air vehicles, air traffic control, or terminals and ground facilities. Each group elected a group leader and the class as a whole elected a project manager.

It was decided that the six month period would be divided into three phases; the initial investigation phase, alternative evaluation phase, and

execution and report writing phase.

New leaders would be elected for each phase. It was also established that each group would present a preliminary report at the midpoint of the second phase. Finally a report editor was selected and an interface committee was formed to facilitate the flow of information between groups.



INTERFACE COMMITTEE

Figure 1.3

At the end of the final phase, formal presentations of this report were offered to various interested groups from government and industry.

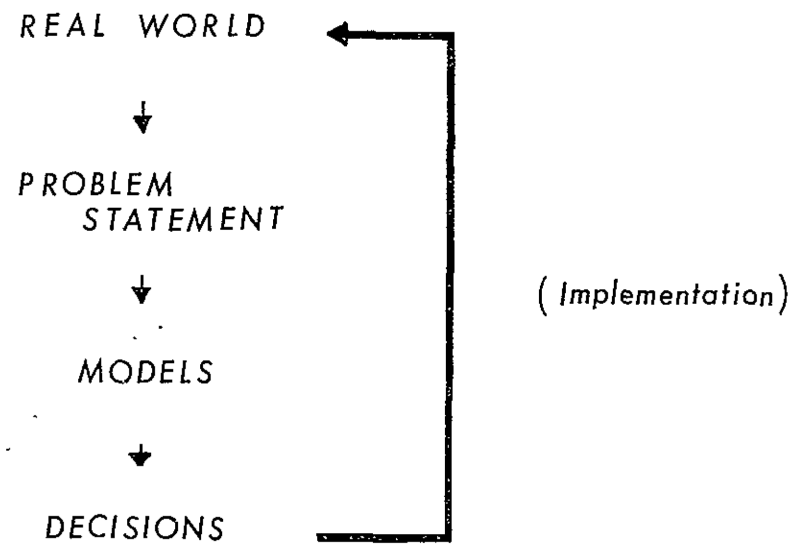
The Table of Contents contains the authors of their respective sections of the report. A list of the graduate participants may be found in Appendix 1-B.

CHAPTER 2

SYSTEMS ANALYSIS

2.1 Systems Approach

The systems approach to a design problem is one in which all the elements of the system to be designed are studied in relation to each other and to their enviornment. The combination of elements which renders the entire system most cost-effective is implemented.



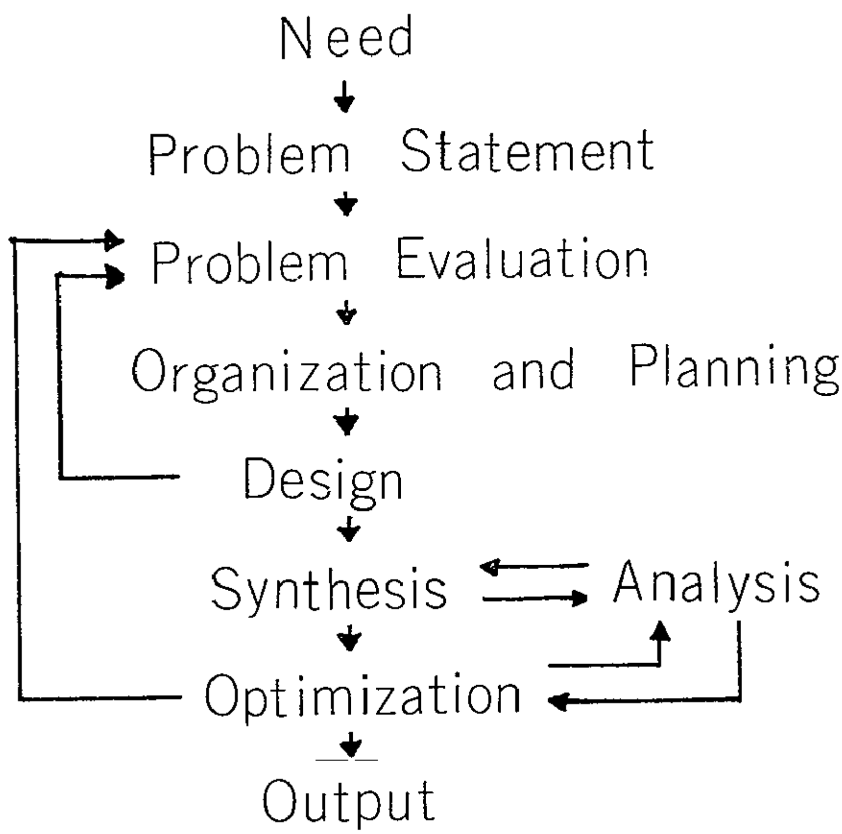
DESIGN PROCESS

Figure 2.1

Figure 2.1 is a diagram of the design process used. The real world generates a need. Careful analysis of the need results in the problem statement. Mathematical models are used to simulate each element of the system and the environment. These models allow the design team to "operate" each possible solution to the problem and to determine the cost-effectiveness of each alternative. These facts are considered along with the irreducible intangibles involved and a decision is made on which alternative is to be implemented. Implementation of a given alternative generates a new need

and the cycle is repeated.

The iterations made in establishing each design alternative are depicted in more detail in Figure 2.2 below.



ESTABLISHMENT OF DESIGN ALTERNATIVES

Figure 2.2

The Systems Approach requires a final decision on the designer's part which necessarily must be based on fact and judgement. It is a fundamental principle of Systems Engineering that judgement should not be substituted for available facts.

2.2 Application to the Air Transportation System

After analysis of the problem by students both individually and in small groups, the formal problem statement was made.

> "The problem is to design a transportation system to move people and their baggage by air between major cities in the continental United States in the 1975-1985 period."

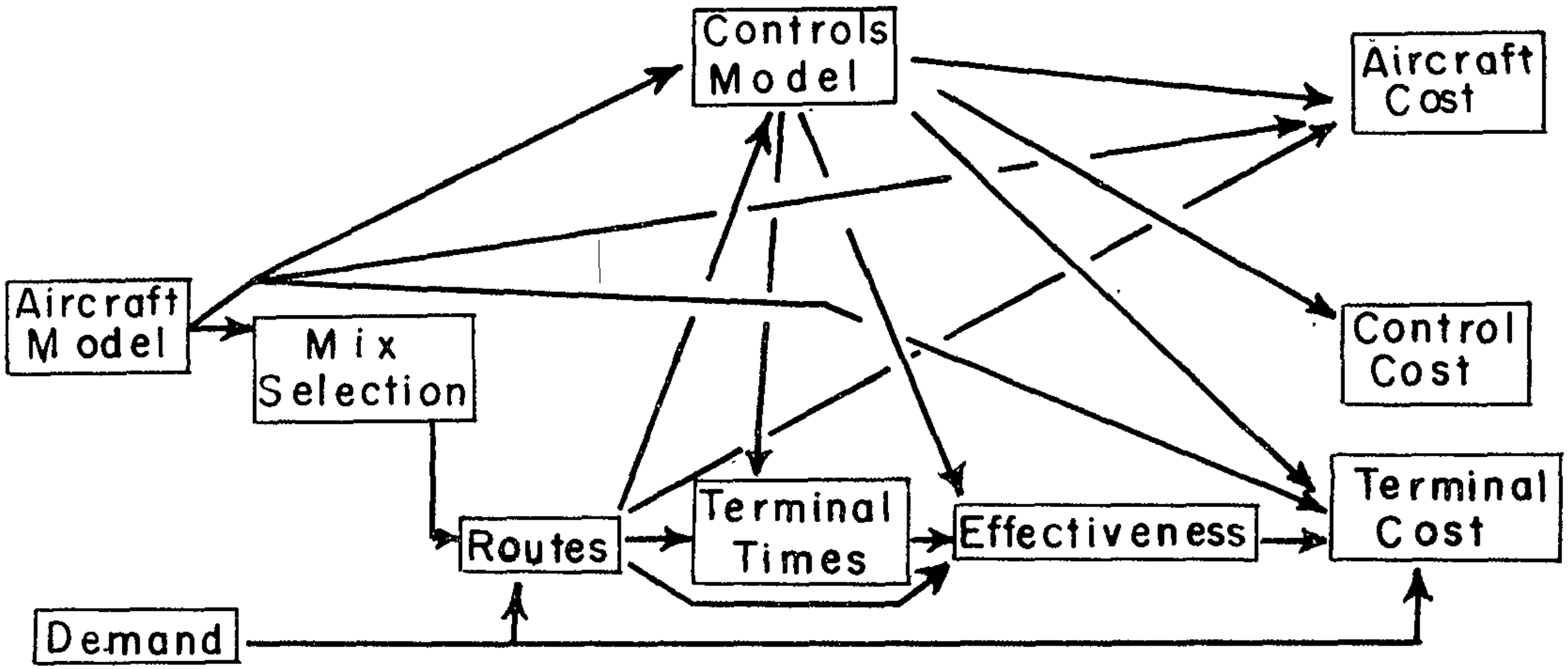
At this point the jobs each group was to perform were well defined. The Route Group was to develop models simulating travel demand and route structure. This group was also to provide the class with information on city populations and land costs. It was the goal of the Terminal Group to design and simulate mathematically terminals and ground facilities for all forms of aircraft considered. The Air Traffic Control Group was to design and simulate mathematically various air traffic control systems and runway configurations. The Air Vehicle Group had the job of designing and modeling mathematically all the aircraft to be "flown" in the system.

After each group had an opportunity to study their particular tasks for some time the following list was made of the variables to be investigated.

(1) Aircraft Design Range
(2) Aircraft Cruise Speed
(3) Aircraft Passenger Capacity
(4) Required Runway Length
(5) Aircraft Mix (The number of aircraft of various types flown in the system).
(6) Terminal Location within a City
(7) Terminal Combinations within a City
(8) Average Aircraft Delay
(9) Aircraft Separation on Runway
(10) Runway Separation

Figure 2.3 shows how the individual models produced by each group interfaced with those of the other groups to model the entire system.

Each arrow represents the flow of data cards between models. The Controls Model, for example, received data from the Aircraft Design and Routes models and provided information to the Terminal Time, System Effectiveness, Terminal Cost, Control Cost and Air Vehicle Cost models.



MODEL INTERFACING

Figure 2.3

The system was quite large, requiring nearly ten hours of computer time and 60,000 data cards to process 189 alternatives.

The data obtained from these models was plotted and analyzed and the most cost effective alternative chosen.

CHAPTER 3

ROUTE AND DEMAND MODELS

3.1 Introduction

In developing a systems analysis for common carrier air transportation in the United States, two of the most significant aspects involve forecasts for air transportation demand and route selection and assignment of aircraft for the forecast period.

The forecast of air travel demand serves as primary input both for the route model and for the terminal cost model. Route selection is a function of the demand to be served. Without an accurate forecast of demand, the route structure selected may be faulty, and the number and type of aircraft required in the horizon year may be considerably in error. Similarly, the cost of terminal facilities at major air hubs represents a major investment for the local community, the federal government, and the air carriers themselves. An accurate demand estimate is essential not only for determining the ultimate size and cost of the terminal, but also for staging the construction of facilities as demand and traffic increase. The ability to stage such construction is absolutely essential for all parties concerned.

The route model is no less important. The selection of air transportation hubs and the route structure connecting them has a significant impact on congestion to be experienced in the horizon year. It also has a significant impact on future air traffic through the terminal. As such, the route structure and the assignments of aircraft have important bearings on the cost of air traffic control. This is of major concern to those governmental agencies charged with controlling domestic airspace. Finally, the route model provides a framework for evaluating the feasibility for certain aircraft types. This is particularly significant with respect to future

developments of STOL (Short Take-Off and Landing) aircraft. By forecasting the number and type of aircraft needed in the horizon year, information will be provided the aircraft industry for establishing important priorities regarding the development of various aircraft types.

The next section of this chapter outlines the methodology surrounding the demand model selected for this systems analysis. Following that is a similar development for the route model selected.

3.2 Demand Model

The demand model was selected after a review of the literature in the field. Although some problems were experienced in calibrating the model, it has been proven to be quite effective in forecasting demand.

3.2.1 Purpose of the Demand Model

Design requirements for a possible 1975-1985 air transportation system include an estimate of the number of passengers that can be expected to fly. Furthermore, it is necessary to establish the various ranges over which different groups will fly.

After a study of the existing demand models, the concept of a travel generator model evolved. A travel generator model would forecast or generate a travel demand between locations based on characteristics of the location. This estimate is not a prediction of the actual future demand, but only a forecast of what the demand could be. Because of the tremendous uncertainties involved in future traffic forecasts, the final system should be tested against sensitivity to this demand factor.

3.2.2 Variation in Demand

Air travel demand does not remain constant with time. Seasonal, daily, and hourly peaks are almost always experienced. While the demand model was calibrated for average daily demand, some knowledge of the variation about

this mean was deemed essential for proper terminal design. Following are the highlights of these investigations into demand variations. Details of the investigations may be found in Appendix 3-A.

3.2.2.1 Seasonal Peaks

Two pronounced seasonal peaks occur in air travel demand. One is in the summer months, reflecting a higher demand for vacation travel during this period. The second peak occurs during December. This represents a high demand for air travel during the holiday season. Especially noteworthy is the fact that these peaks represent seasonal demands for non-business travel.

3.2.2.2 Daily Peaks

Peaks in air travel demand during any given week represent a demand for business travel. Peaks are most noticeable on Mondays and Fridays, the beginning and end of the business week.

3.2.2.3 Hourly Peaks

Peaks in air travel demand throughout an average day occur in the morning and evening. This represents a combination of business and non-business demand.

3.2.2.4 Ratio of Peak Day to Average Day

This figure is the most significant one for air terminal and control system design. In 1967 the peak day averaged 70 percent higher than the average day for the country as a whole. Specific values of this ratio, for individual cities, are tabulated in Appendix 3-A.

3.2.3 Review of Existing Models

The limited amount of time allotted to examination of demand models dictated a quick review of the literature available. Several demand models were examined and are reviewed below.

Systems Analysis and Research Corporation has developed a model for the northeast corridor which applies relationships between socioeconomic factors and travel volume [1]. All modes of transportation were considered and forecasts

were made for only selected city pairs in the northeast corridor. This model was not considered since the data for cities outside the area was not readily available.

Massachusetts Institute of Technology has made use of the gravity model to predict traffic volume between any two population centers on the basis of population and distance [2].

Lockheed-Georgia Company expanded the model suggested by MIT to include the capability of passengers to travel (income of origin) and the desirability for travel (attractiveness of destination)[3]. Because of the limited time available and the uncertainty of the forecast, the Lockheed-Georgia Company model was selected for use in the project. The model has been modified somewhat, to conform to the specialized requirements of this study.

3.2.4 Discussion of Demand Model Algorithm

As mentioned, the model selected is a modified gravity model. Modifications include adjustments to dampen the demand for very short flights, to reflect the rapid increase in air travel as compared with population, and to include the propensity and ability of people who fly.

3.2.4.1 Inputs to the Model

Inputs to the demand model consist of information about each of the 144 cities studied. Such information includes population for the last two censuses, average city income, latitude and longitude of the city, and percentage change in air travel demand. The model then uses these inputs to calculate demand.

3.2.4.2 Calculation Procedure

The model itself predicts demand between two cities in direct proportion to the product of the cities' populations and inversely as the distance between them raised to a power. An adjustment is made to dampen the demand for very short trips.

The model first computes the great circle distance between all city pairs, using the latitude and longitude of each city provided as input. The model then projects population for each city using the census figures, by three different methods. An average increase is then calculated for each city. Percentage change is then calculated for each ten year interval to the year 2000.

A relative income factor is developed, which is the ratio of average city income to the smallest average income for any city under study. Demand is then calculated for each ten year increment, adjusting the figure by the income factor and the difference between the average rate of air travel demand growth and the rate of population growth in the origin and destination city. Summaries are then prepared showing air travel demand for the years 1970, 1980, 1990, and 2000. Initially, constants similar to those used in the Lockheed study cited previously were used. These constants were adjusted to make the forecasts for 1970 slightly higher than known figures for recent years. Once these constants were adjusted, final demand summaries for future horizons were prepared.

3.2.4.3 Reduced Area Demand Model

Initial calculations for the demand model were made for 144 Urbanized areas in the United States. Consideration of the programs that might use this data required that a smaller network be considered as a typical area. Demand summaries were used to construct a network of 11 cities for use in the route model. Since a reduction of this nature could greatly influence the results of the study, it is recommended that a sensitivity analysis of the final results be considered for this program.

3.3 Route Model

The output of the demand model serves as input to two models. Demand figures are necessary for computation of terminal costs. Aspects of this pro-

blem are covered elsewhere in this report. Demand figures are also necessary for selecting a route structure, loaded with various types of aircraft. Aspects of this problem are discussed below.

3.3.1. Importance of the Route Model

The route model is a key protion of the total systems study presented in this report. Specifically, it is the function of the route model to furnish aircraft for a known route structure from a pool of available aircraft types in such a manner that the demand for air travel at each node in the structure is satisfied in some satisfactory manner. In making these assignments, moreover the particular strengths and weaknesses of each aircraft type should be exploited. However, the model should not be biased in favor of a particular type of aircraft, to the exclusion of all others.

The assignments of aircraft to routes is not an end in itself. These assignmnets are input for many of the remaining models in the systems analysis. Specifically, it is the function of the route model to provide input for determining the

(1) Control System

(2) Aircraft Cost

(3) Terminal Time

(4) System Effectiveness

Establishing a methodology for the route model, therefore has a significant impact on the other models in the study.

3.3.2 Optimal Seeking Approaches for Loading the System

In establishing a methodology for loading the system, some optimal method is obviously to be preferred. Following is a brief discussion of some of the general optimal seeking methods available. In each case, the reasons for rejecting it as a method will be explored.

3.3.2.1 Traffic Assignment Algorithms

It would appear that the problem at hand is in some sense related to the loading of a traffic network during the transportation planning process for urban areas. The methodology used there is assignment by minimum travel time over the network from the point of origin to the point of destination. Such assignments consider a wide variety of factors surrounding the network, including the capacity of each link in the system.

There are two reasons why this method is not suitable for the purposes of this study. One reason relates to the difference in characteristics of the traffic network and the airline route structure considered here. The second relates to the vehicle considerations mentioned previously.

In the traffic assignment algorithm the selection of a particular assignment path is strictly based on travel time. Therefore. the process is one of selecting a path through a maze. The number of alternative assignments is very large; the algorithm selects the best alternative from this large set. In the airline route problem the number of alternatives is small. Moreover, penalties must be assessed for flights containing many short hops. Non-stop flights should be emphasized. Therefore, the airline problem consists of satisfying a demand from a very limited number of alternative routes. The problem is more one of assigning vehicles to a known route structure than one of selecting a route to satisfy a demand.

In the traffic assignment algorithm no consideration is given to differences in vehicle types, since none exist. With few exceptions, demand is satisfied with one class of vehicle, the automobile. In the airline case, the number of alternative vehicles is considerable. The route model must assign these vehicles in some manner to satisfy demand. In this respect, the traffic assignment process and the route selection and loading process are completely opposite.

3.3.2.2 Linear Programming Approaches

A second class of models which have possibilities for the problem at hand are the linear programming models. These models attempt to optimize some linear functions subject to a set of linear constraints. Two of these models will be discussed.

3.3.2.2.1 The Transportation Problem

A general solution method has been developed for satisfying the demand at a set of locations from a supply at a second set of locations. This general method has been called the transportation problem. It is, however, totally unsuited for the purposes of this study. In the airline case presented here, the demand for air travel at one set of cities is satisfied by the destinations at a second set of cities. In this respect, the problem here is similar to the transportation problem. However, the crucial difference between the two is that in the transportation problem it is not important where the demand is supplied from. The algorithm merely supplies the demand in a least-cost manner. In the airline case presented here, it is important that air travel be supplied from a particular origin to a particular destination. This is completely contrary to the formulation of the general transportation problem.

3.3.2.2.2 The General Linear Program

Linear programming techniques provide a general optimal-seeking procedure for solving a wide variety of problems. The general method has been computerized, so that rapid solutions to complex problems are possible.

As mentioned previously, the general linear program optimizes some linear function subject to a set of linear constraints. In attempting to apply this general procedure to the problem at hand, severe problems developed in formulating constraint functions which would conform to the general solution method. This complexity results from the characteristics of the airline problem under study.

In the airline problem, the flight of an aircraft over a specific route is not a static event, but rather a dynamic one. At each destination along the route, certain passengers embark, some debark, and some remain enplaned. Penalties must be imposed for those routes with many stops, reflecting the desire of passengers to fly non-stop. As such, the number of variable elements which must be optimized in this general case quickly becomes unreasonable.

In addition to the constraints surrounding the route structure, constraints are necessary to prevent bias in the selection of aircraft types. Specifically, it was felt that the general linear program would always make assignments to those aircraft types with the least cost per passenger mile. These would generally be the "jumbo-jets" currently scheduled for entry into commercial aviation in the near future. Therefore, constraints were necessary to prevent bias in favor of the large aircraft. The combination of the route constraints plus the aircraft constraints made the general linear programming procedure too unwieldy for further consideration.

3.3.3 Route Model Methodology

At this point it was decided that a general solution procedure was not available to satisfy the requirements of the problem at hand. A special-purpose procedure was developed which fulfills the requirements of this study. Following is a brief description of the inputs required by this model and its solution method. For a more detailed explaination of the procedure see Appendix 3-B.

3.3.3.1 Inputs to the Model

Two types of input are required for this model. These relate to the aircraft available for satisfying the demand for air travel and to the route structure over which these aircraft must fly.

For each alternative STOL aircraft considered in this study, an aircraft mix consisting of that STOL and a CTOL (Convential Take Off and Landing) aircraft was available for allocation to the route structure. Ideally each such mix would reflect the cost and operating potential of the given STOL craft for a complex network of routes. Since the same CTOL aircraft would be used in all mixes and since its only function was that of carrying passengers for ranges beyond the STOL, it was felt that it should not bias any mix or set of mixes. Such characteristics as speed, capacity, and cost per flight mile are input for each aircraft type.

The route structure which will be loaded with a particular mix of aircraft is a second input to this model. Each such route may have up to four legs. Each route is numbered for identification. Along with the route number, such information as distance between cities along the route, and demand at each city are provided.

3.3.3.2 The Route Model Algorithm

The procedure for loading the network is as follows. The particular STOL aircraft being considered is first assigned to all direct routes within its range. The number of flights assigned to a particular route is proportional to the demand on that route and inversely proportional to the capacity of the aircraft. Next the CTOL aircraft is assigned to the remaining direct routes which could not be flown by the STOL aircraft. This method of assignment reflects a preference reserving STOL range routes for STOL aircraft. Second, it reflects a preference for direct flight over intermediate stop flights.

As the above procedure is executed the demand between the cities is reduced as flights become available. It was decided to reduce the demand by some fraction of the available seats to reflect the traditional load factors encountered in airline service. This fraction is also the

proportionality constant used in the assignment of a specific number of flight to a given route.

When the demand is insufficient to fill the given fraction of a plane or when the remaining demand is insufficient to add another flight to a specific route, intermediate-stops are considered. STOL craft are first assigned to two-legged and three-legged routes. Assignment of flights continues until demand has been completely reduced or the cost-per-passenger for the additional flight become excessive. CTOL craft are then considered for the longer two and three legged routes beyond the range of the STOL craft.

While the above methodology is not optimal seeking, for the purposes of this study it should be adequate to avoid biasing the results.

CHAPTER 3 REFERENCES

[1] Systems Analysis and Research Corporation, Demand for Intercity Travel in the Washington-Boston Corridor, Boston: 1964.

[2] Massachusetts Institute of Technology Flight Transportation Laboratory, A Systems Analysis of Short Haul Air Transportation. Technical Report 65-1. Cambridge: August, 1965.

[3] Lockheed-Georgia Company, Mass Air Transportation Study Final Report. Marietta, Georgia: 1968. (125)

[4] U. S. Bureau of the Census, County and City Date Book, 1962. U.S. Government Printing Office, Washington, D. C., 1962.

CHAPTER 4

AIRPORT TERMINALS AND GROUND RELATED FACILITIES

4.1 Introduction

The present national air transportation system has not been developed with total cost effectiveness in mind. The terminal model, a mathematical representation of a real life terminal subsystem, will evaluate the cost effectiveness of various alternatives for future airport systems.

The primary objectives of the terminal model are to determine the ground access time to and from the CTOL (Conventional Take-off and Landing) airport or STOL (Short Take-off and Landing) port; and to determine the total construction, design and operations costs for the cities and aircraft mixes tested. The secondary objectives of the model are to consider alternate ground transportation modes, various terminal configurations and increased automation of baggage handling.

Airports were evaluated to determine those which served the predicted volumes at the least cost. The costs considered were land, terminal building, terminal area, ground access time, terminal operations and maintenance.

4.2 Submodels

4.2.1 Introduction

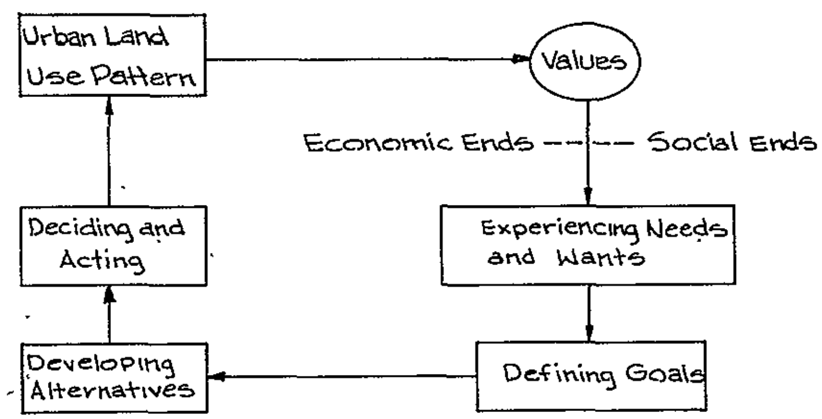
The models for airport costs depended on the development of a land value model, the concept of air traveler's value of time, a passenger process time model, a conventional airport model, and a STOL airport model.

4.2.2 Urban Land Value Model

Land values within the urban area will be important factors in the consideration of airport location. Land value is, to a large extent, dependent upon land-use at the particular location. A complex set of variables is associated with land use. People experience needs and wants, many of which are shaped by social and economic forces.

Whereas the social forces are often very difficult to quantify, economic forces lend themselves to quantification. Within the economic realm, land value is a function of (1) the costs of making the land productive and (2) the income that will be returned from the land. These two factors vary with land use types. Within any applicable constraints, the user who is willing to pay the most for a site will usually occupy it. Aside from the two factors mentioned above, certain sites may have high values for specific types of uses due to their spatial relationships with surrounding facilities.

The urban land-use pattern is, then, the result of economic behavior associated with satisfying the needs and wants of people in the urban land market (Figure 4.1).



THE URBAN LAND MARKET

Figure 4.1

The purpose of the land value model is to provide some basis for decisionmaking in terminal location. The model is not an ultimate predictor and may leave many factors unaccounted for. When dealing with the many structural configurations of urban areas, each one of which is unique, we immediately become aware at the gross over-generalization of any model which purports to indicate land value in any urban area.

The following mathematical formulation was obtained from Samuel E. Eastman of the Economic Sciences Corporation:

$$R = \frac{844 \left(\frac{P}{10,000}\right)^{0.309} A^{0.971}}{(10M)^{0.867}}$$

where: R = price of land (dollars per acre) in 1965 prices.

P = 1960 population of urbanized area, including urban fringe.

A = 1960 urbanized land area in square miles, including urban fringe.

M = distance from CBD in miles.

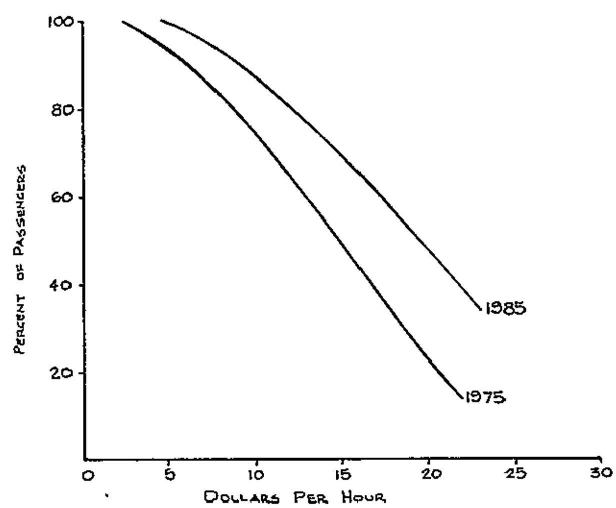
The model has been tested in a number of urban areas. In general it tends to underestimate the true value at the land area under consideration. (See Appendix 4-A).

4.2.3 Air Traveler's Value of Time

The air traveler considers the out of pocket expenses in relationship to the total door-to-door travel time when choosing between modes of transportation. The total cost for a trip, in addition to the ticket cost, includes the cost of traveling to the departure terminal and traveling from the arrival terminal to the actural destination. These additional travel costs are for use of private auto, taxi, limosine or public transportation.

The total travel time is defined as the time between leaving the actual departure point and the arrival at the actual destination. A monetary value is assigned to this time. It is assumed to be some function of the income level of the traveler. In other words, the air traveler's time is money. Therefore, he is willing to pay more for a mode of transportation which saves time. This is called the "value of time" concept.

An analysis of personal and business travel in the Northeast Corridor demonstrates that personal travelers value this time less than their hourly income. On the other hand, business travelers value their time substantially more than their hourly income. Business travelers value flying time at roughly one and one-half times their income. However, the value of time of personal travelers is placed at approximately only one-half their hourly income. Using these assumed values of time along with a 70 - 30 percent split of business and personal travelers, a value of time distribution for air travelers may be derived. [1] The result is shown in Figure 4.2 in 1969 constant dollars. The average percentage of passengers for 1980 is utilized to determine a mean constant value of time for the period 1975-1985 whenever reference is made to the air traveler's value of time.



Air Travelers Value of Time

Figure 4.2

4.2.4 Passenger Process Time

The term process time refers to a combination of several actual times, including:

1. Time moving to the terminal from a parked automobile (or public transportation).
2. Time for ticketing.
3. Time for baggage check-in or baggage claim.
4. Time in transit to correct gate position.
5. Time to board the aircraft.

These five parameters serve as the major components of the process-time model which is incorporated in the overall terminal model.

Several basic assumptions were made in the development of the model. The typical passenger, as used in the model, arrives at the airport in a private auto and parks in the parking lot. He has reservations for a certain flight, but must pick up his ticket inside the terminal. The passenger's baggage is also checked-in at this time. For overall consistency for the various sizes and configurations of airports, it was assumed that the passenger then walks to the correct gate location for boarding the aircraft. With the above assumptions, the times produced by the model should be viewed as the time for a typical passenger to complete everything required between leaving his car in the parking lot and arriving in the correct gate position.

Several of the five parameters mentioned above were set by predetermined conditions. Boarding times were obtained from the group concerned with aircraft types and design. An average boarding time for the expected aircraft types was used. Baggage check-in and ticket clearance times were suggested by one of the major airlines. These times were used as threshold times.

Baggage claim time is based on the expected efficiences of proposed baggage handling systems. The summation of these times -- results in a constant time. The two variable times in the model are the time from auto to terminal and the time to get to the correct gate or boarding location. These variables are based on the number of total daily passengers at the airport, which is an input into the overall terminal model. The functional relationship development is described in Appendix 4-B.

4.2.5 Conventional Airport Model

The cost model for the conventional terminal was based on an analysis similar to that used in reference [3]. The total airport costs were divided into two main parts: land costs and facilities construction cost. The facilities construction costs were further subdivided into three parts: parking lot costs, terminal costs and aircraft operations area costs. It is felt that these subdivisions are sufficiently basic to allow virtually any airport configuration to be considered desirable to have off airport parking. The gross costing model used here will still apply since the model does not specify the location of the parking lot except to say that it is located at approximately the same distance from the city center as the airport. Furthermore, it is difficult to conceive of an airport that would not contain these three elements as they are basic to the very nature of an airport; that is a facility to change people from an air transportation mode to a ground mode.

In the following sections we will examine each of these facilities in some detail. It should also be pointed out here that we are considering not a total cost for capital outlay but rather an annual cost based on amortizing the cost over the useful life of the facility involved. Included in this annual cost is a maintenance cost based on projected extensions of current maintenance costs.

4.2.5.1 Parking Lot

The cost estimating relationship used for airport parking lot construction is:

$$\text{COST} = (1.3)\ (280)\ (0.734)\ (\text{TPHP}) \qquad (1)$$

where:

COST = Total annual cost for airport parking in 1969 dollars excluding land acquisition cost.

TPHP = Number of typical peak hour passengers.

In this relationship 280 is the number of square feet required per parking space [4]; 1.3 is the number of parking spaces required per typical peak hour passenger [5] and 0.734 is the total annual dollar cost per square foot of airport parking structure. This number is derived based on a concept of a one level parking lot so that the initial cost is a paving cost of $2.00 per square foot. Amortizing the initial structure cost over a useful life of 20 years, using an interest rate of 10%, and adding a $0.50 per square foot annual cost gives the stated figure [3]. It should be noted here that equation (1) does obviously not include any income factor. In fact, as indicated in many reports, the operation of a parking lot is one of the most profit making enterprises in which an airport many indulge. It is far from being just self supporting, and in many cases parking revenue may contribute significantly to lowering airport operations cost.

4.2.5.2 Terminal Building

The cost estimating relationship for the airport terminal building is:

$$\text{COST} = (150)\ (6.27)\ \text{TPHP} \qquad (2)$$

where:

COST = Total annual cost for airport terminal in 1969 dollars excluding land acquisition costs.

TPHP = Number of typical peak hour passengers.

The factor (150) is the number of square feet needed by each typical peak hour passenger. There is some considerable discussion of what value this factor should assume. It appears that the value of 150 provides a good compromise for the wide range of airports to be considered. The factor $6.27 is the total annual cost per square foot of terminal structure. The value is based on an initial estimated construction cost of $45 per square foot amortized over a twenty year useful life with an additional $1.00 per square foot annual cost [7].

It should be noted that once again there has been no attempt to include the revenue producing elements of a terminal. Most airports for example receive revenue from rental fees paid by restaurants, stores, car rental agencies and other non-airport related functions. It was not possible to estimate these revenues in any realistic way and hence they were not included.

4.2.5.3 Aircraft Operations Area

The airport operations area includes runways, taxiways, apron and gate areas. The cost estimating relationship is:

$$\text{COST} = 0.484\ (200)\ \text{RUNL} + 75\ (\text{RUNL}) + 1800000\ \frac{\text{TPHP}}{8000} \qquad (3)$$

where: COST = Total annual cost for the aircraft operations area in 1969 dollars.

RUNL = Total linear feet of runways

TPHP = Number of typical peak hour passengers

It was realized early in the analysis that the number of runways, their lengths and general configurations was more the province of air traffic control than terminal design, but it was also true that the airport model would need to include the construction costs of the runways. Therefore, the

total linear feet of runway is provided as input to the airport costing model. In equation (3) the first term is runway structure costs and the third is apron and gate area construction costs. The factor 0.484 is the total annual cost of pavement. This figure is obtained by taking a $2.00 per square foot initial cost amortized over a twenty year useful life and adding a $0.25 per square foot annual maintenance cost. The runway area to be paved is calculated assuming a 150 foot runway width (as recommended by the FAA for large jet aircraft) with an additional 25 feet of asphalt on each side. Similarly the taxiway area is calculated assuming a 75 foot width and assuming that the length of taxiways is approximately the same as the the total runway lengths. The parking apron area is calculated based on the fact that an apron 3000 feet by 600 feet is capable of handling about 8000 typical peak hour passengers. Thus, for an apron to accommodate some other number of typical peak hour passengers a fraction of the 8000 TPHP area is required. This is a linear relationship and, of course, will break down for very low values of TPHP. However, for this analysis it is considered to be accurate enough.

It should be mentioned here that several elements of aircraft operations are ignored by this model. It was agreed that the costs for instrumentation of the runways would be calculated by air traffic control. The costs of hangars and servicing facilities was ignored because it was felt that plans for the future airport are too uncertain to include them. For example, we have heard of plans to perform all maintenance at one central airport that does not handle commercial traffic and this would eliminate these costs from the model. In addition, it was felt that servicing facilities costs would certainly be borne by the individual airlines and thus come under the same category as equipment which is not included in the analysis either.

4.2.5.4 STOL Runways

It is recognized that at times it may prove necessary to have a STOL runway located at the CTOL airport. The ability to include this option is built into the cost model by recognizing that the major additional cost for the STOL operations would be that due to the STOL runways themselves. This is so because the terminal building and parking lot may simply be scaled up in size to accommodate the additional STOL passengers while the STOL runway is fundamentally different from a conventional runway. Thus the STOL runway cost model is:

$$\text{COST} = 3{,}500{,}000\text{N} + [200000 + 2.69(\text{TSP})](13.972)(0.117) \tag{4}$$

where: COST = Total annual cost for STOL runways

TSP = Number of STOL typical daily passengers

This relation was obtained from Reference [4] and is explained fully there.

4.2.5.5 Calculation of Land Required

For each of the above three segments a certain amount of land is required to accommodate the operation. The land required for the parking lot is simply:

$$(\text{LAND})_\text{P} = (1.3)\ (280)\ \text{TPHP} \tag{5}$$

where the factors are as described before in the construction costs section.

The land required for the terminal is given by:

$$(\text{LAND})_\text{T} = \frac{180}{\text{S}}\ \text{TPHP} \tag{6}$$

Here 180 represents the number of square feet of terminal space required per passenger. This number is obtained by taking the basic passenger requirement (150) and adding 20% for landscaping and building construction. In the above expression "S" is the number of stories in the terminal (usually 1 or 2) and TPHP is as defined before.

The land required for aircraft operations is given by:

$$(LAND)_{AO} = (RUNL)\ (200) + (RUNL)\ (75) + 225\ (TPHP) \tag{7}$$

where the symbols are as defined before in the aircraft operations cost section. If STOL runways are required then the land needed for them is just:

$$(LAND)_{STOL} = (2000)\ (200)\ N \tag{8}$$

where N is again the number of STOL runways. Here we assume a 2000 foot nominal STOL runway length.

Now when the air traffic control group specifies a runway configuration they also specify a minimum land area purchase since it is necessary to purchase a block of land large enough to contain the runways. (Not too many real estate agents are willing to sell a strip of land 200 feet wide and 2 1/2 miles long!!). Now it is quite possible that this same block also has enough excess land to accommodate the terminal, parking lot and airport operations area. Thus, it would be foolish to include a land purchase for this case in the cost model. On the other hand it is not resonable to expect the terminal and parking lot to exactly fill the excess area in the block since this would impose severe limitations on shape and location of the terminal and parking lot. Thus, in the model, the purchase of additional land above and beyond that needed for the runway configuration is only made when the land needed is greater than 75% of the excess land left in the runway configuration. Using this method a total land purchase requirement is generated. It is felt that this number is more realistic than one obtained by simply adding the land requirements of the various elements.

Once the total land required has been found then the cost is simply

$$COST = (TOA) (PRICE) (.10) \tag{8}$$

where: TOA = Total land area in square feet

PRICE = Land Price in 1969 dollars per acre

Here (.10) is a capital reduction factor applied to the initial cost of land having an infinite useful life. Notice that there are no annual costs associated with the land.

4.2.5.6 Calculation of Model Parameters

As may be seen by considering the models used, there are two main parameters involved: land cost and number of typical peak hour passengers. Calculation of these two parameters is discussed below.

4.2.5.6.1 Land Cost

A land cost model similar to that used in section 4.2.2 is used here. A number of checks on this model were performed to check its validity and while the results were by no means perfectly accurate the general conclusion was that for studies of the type we are performing here this model is adequate.

The 1985 urban area population is provided as an input from a model development by the demand and route structures group especially for this study. The 1985 area of the urban area and distance of the airport from the central business district (CBD) is provided by a city model already used in this study and discussed in the section of this report dealing with the location of a STOL port. In all cases it is considered that the airport is located on the fringe of the city.

It is realized that applying this model to a city far in the future may be a little inaccurate. However, it is felt that in the next twenty years city expansion will be relatively linear. That is growth in an out-

ward direction will be mirrored in a corresponding increase in land values at a given distance from the CBD, and this growth is expected to be especially stable at large distances from the CBD. Hence while it may be argued that close to the CBD land values may over the years fluctuate or even (as in the case of Oakland from 1950 - 1960) decrease it is felt that for an urban fringe airport this model will be realistic within the accuracy of this analysis.

4.2.5.6.2 Typical Peak Hour Passengers

The demand model (Chapter 3) develops a projected annual demand for the CTOL airport. In reference [3] a recommendation is made as how to convert this annual demand into a number of TPHP. It is:

$$\text{TPHP} = (\text{TAP})\ (\text{G}) \tag{11}$$

TAP = Total annual passengers

and G is given by the following table:

TAP					
	TAP	≧	20,000,000		.035
20,000,000	≧	TAP	≧	10,000,000	.040
10,000,000	≧	TAP	≧	1,000,000	.050
1,000,000	≧	TAP	≧	500,000	.065
500,000	≧	TAP	≧		.120

TABLE 4.1

4.2.5.7 Summary

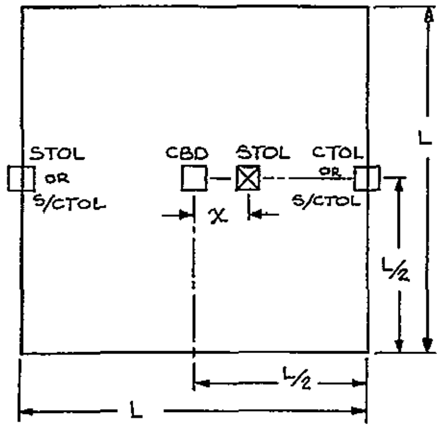
The above model will, within limits, cost a typical CTOL airport and include the basic functional relationships between their cost and the factors influencies the airport (size, location, air traffic control consideration

etc). As such it is felt that this model is adequate for an initial systems design application such as this study dictates.

4.2.6 STOL Submodel

The development of a model for costing the development of a STOL port (an airport for short takeoff and landing craft), was hampered by the fact that none now exists. This problem was overcome by relying on costs developed by McDonnell Aircraft (See references [4] and [8]). The McDonnell Corporation also had determined the distribution of aircraft users and this was simplified for our model. The assumptions made in the development of the model are:

1. The urban area may be considered as a square.
2. Trip ends of air travellers are uniform over the area with an additional "spike" concentration of 30 per cent in the CBD (Central Business District).
3. The Central Business District is at the center of the square and for computations is assumed to be the origin of cartesian coordinates.
4. The conventional airport (CTOL) is centered on a side. This same orientation is true of S/CTOL (conventional airports with runways for short take-off and landing craft).
5. The short take-off and landing airports (STOL) are located somewhere on the line passing thru the CTOL and/or S/CTOL and the CBD, but within the square. (See Figure 4.3).

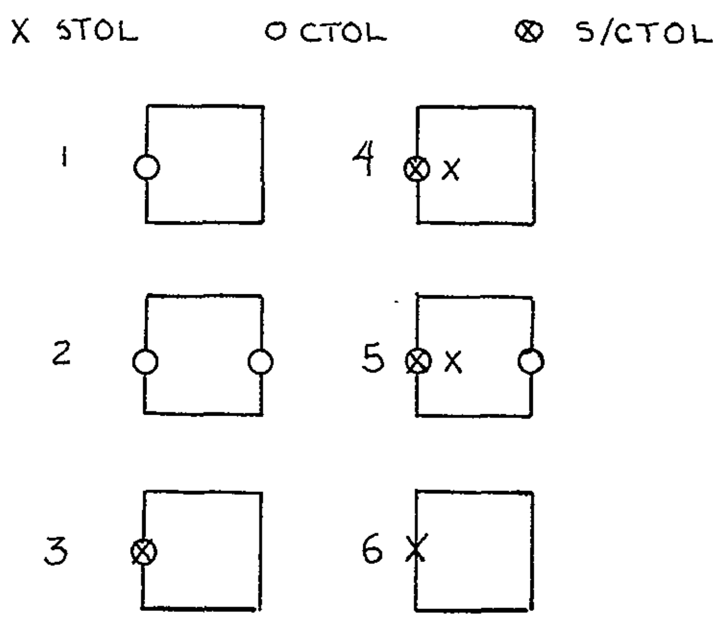


CBD = Central Business District
STOL = Short Takeoff and Landing Port
CTOL = Conventional Airport
S/CTOL = Conventional Airport With STOL Facilities

Typical City
Figure 4.3

6. Air passengers will make use of the port which gives minimum ground time since all operations at equivalent facilities in a city are the same.

7. At a given city, only one of six sets of ports is possible. (See Figure 4.4).

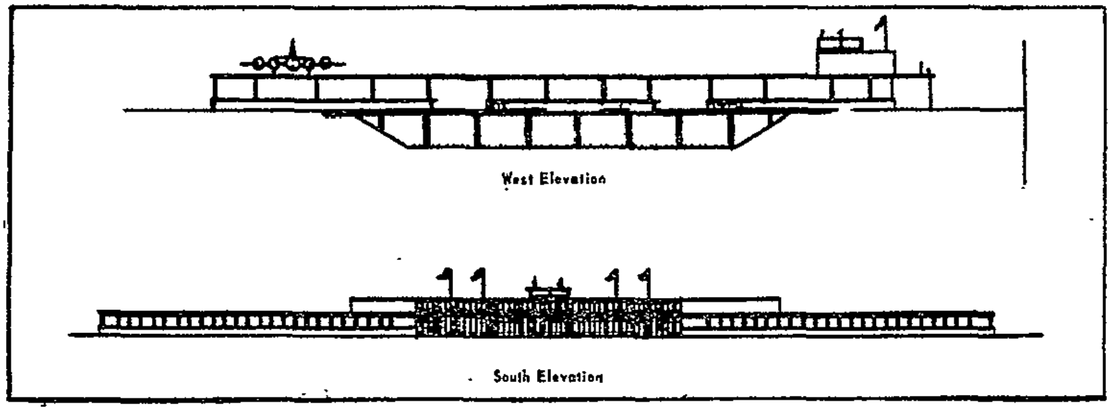


Airport Arrangements
Figure 4.4

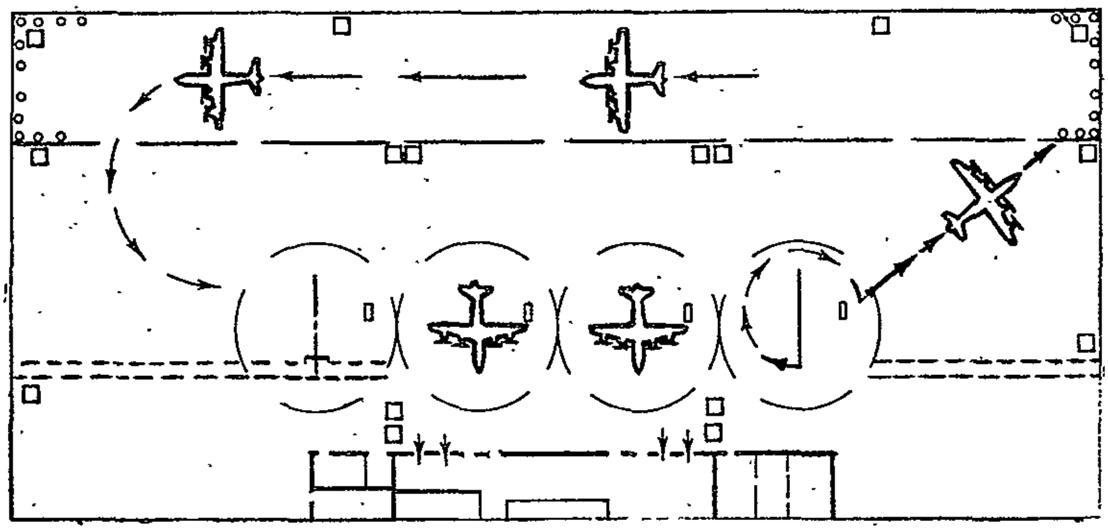
4.2.6.1 Model Development

The basic configuration developed by McDonnell (Figure 4.5) was reduced by subtracting cost of design, contingency, and the cost directly associated with each gate. The cost that remained was considered the cost of the basic terminal building. Each gate was assumed to handle 2000 persons and the cost for a particular terminal became the basic cost plus cost of gates at 2000 persons per gate plus design cost plus contingency.

BASIC STOL PORT CONFIGURATION



STOL Port Elevation



STOL Port Aircraft Operational Area

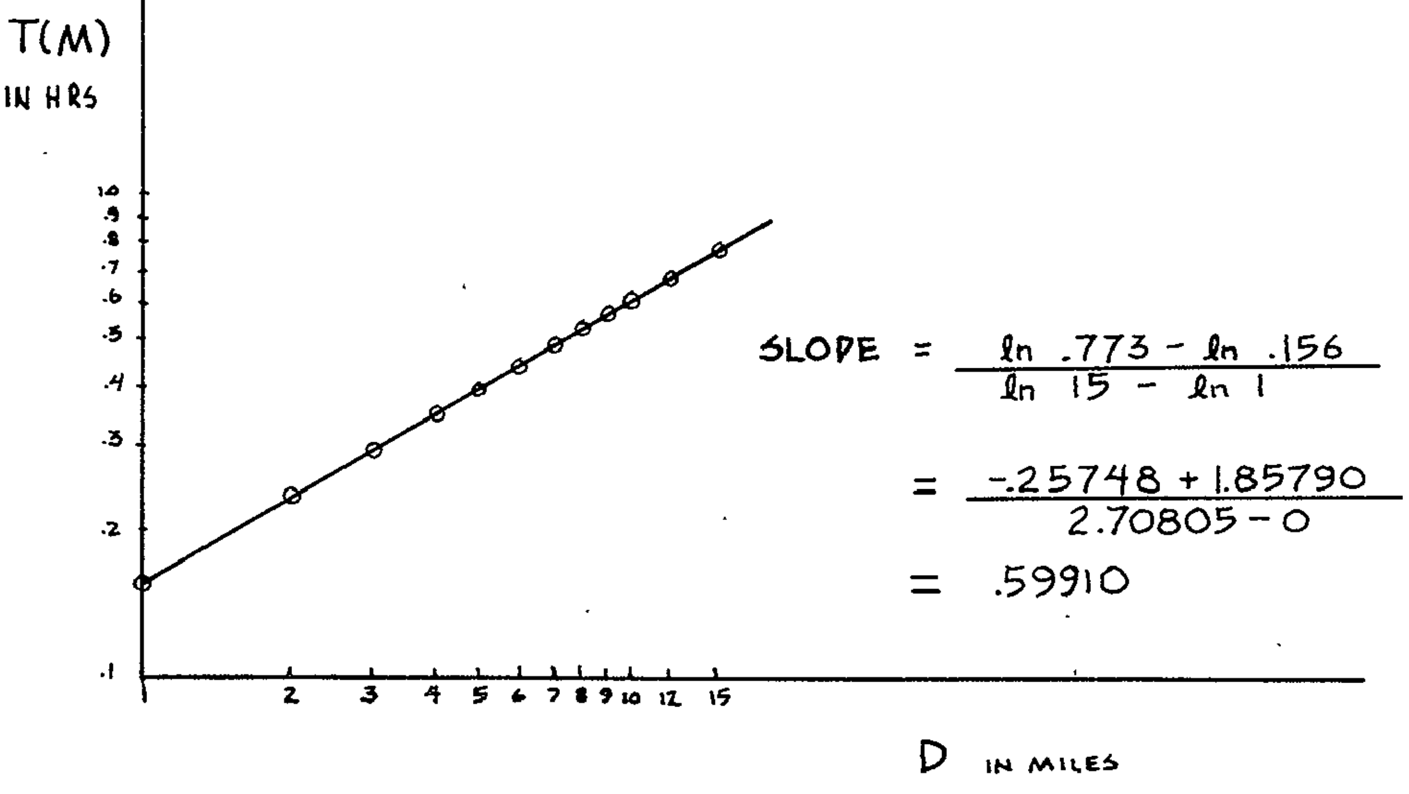
courtesy: McDonnell Aircraft

Figure 4.5

Curves for operations and maintenance were also developed by McDonnell Corporation and the formulae to fit these were determined and applied to the actual demand.

EQUATION:

$$\ln T = -1.85790 + .59910 \ln D$$
$$T = e^{-1.85790} \quad e^{\ln D \cdot .59910}$$
$$T = e^{-1.85790} \quad D^{.59910}$$
$$T = .156 \ D^{.59910}$$



$$\text{SLOPE} = \frac{\ln .773 - \ln .156}{\ln 15 - \ln 1} = \frac{-.25748 + 1.85790}{2.70805 - 0} = .59910$$

AVERAGE DISTANCE AND TIME TO TERMINAL

Figure 4.6

The access cost of reaching the terminal was determined by evaluating the average distance to the terminal (See Appendix 4-C). The curve in Figure 4.6 was then applied to obtain time and the average value of travelers' time was applied to this figure to get cost. (See Section 4.2.3).

4.2.6.2 Conclusions

It is possible to approximate the costs of terminal construction and operations by use of mathematical formulae, and terminals can be fitted to the needs of particular urban areas.

4.2.6.3 Recommendations

1. Further research into development of models that do not need to operate under the very limiting conditions used in this model.

2. Evaluation of unconventional terminal layouts is necessary.

3. Inclusion of costs due to noise or other socio-political problems associated with airport operations is necessary.

4.3 CTOL - STOL Terminal Model

The model for the terminals is based on the calculations and assumptions explained in Section 4.2 of this report. The model is a combination of time and cost calculations with the final solution based on lowest total cost including a value for time (Figure 4.7). A flow diagram of the effectiveness version of the model is shown in Figure 4.8. This diagram graphically explains the operation of the effectiveness of the model. It is noted that for the class problem, two versions of the terminal model were required. The version other than effectiveness of the model is the cost version. The changes in the flow diagram for the cost version are shown in Figure 4.9. The basic difference between the two versions is the output. The effectiveness version has an output of access and process times for the CTOL and STOL terminals. The cost version has an output of total dollar cost for the CTOL and STOL terminals in all of the cities investigated.

The terminal models were programmed for computer use in the FORTRAN IV language. A complete printout of the effectiveness version of the terminal

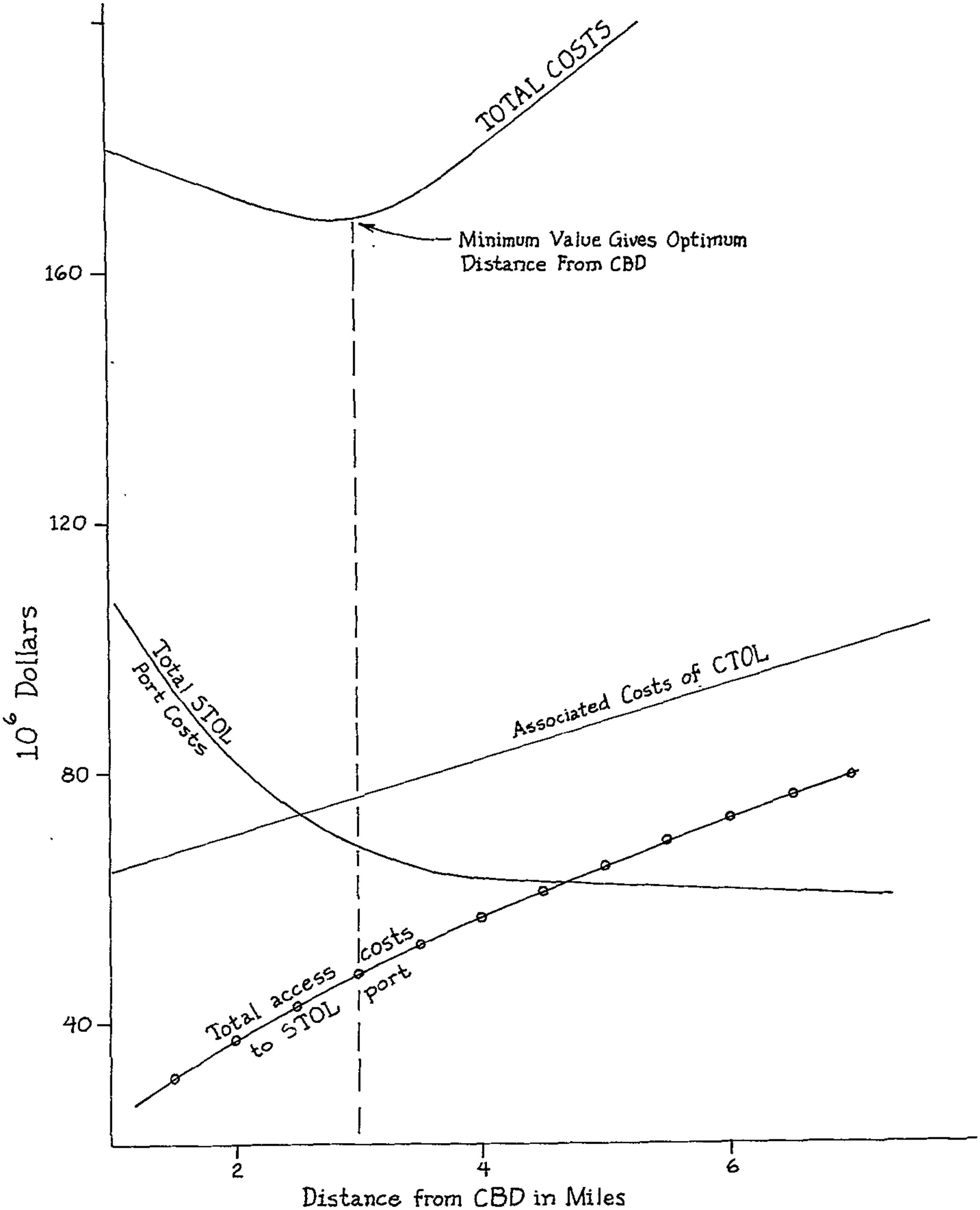


Figure 4.7

Optimum Location of the STOL Port in an Urban Area

CTOL-STOL TERMINAL MODEL

FLOW DIAGRAM
EFFECTIVENESS VERSION

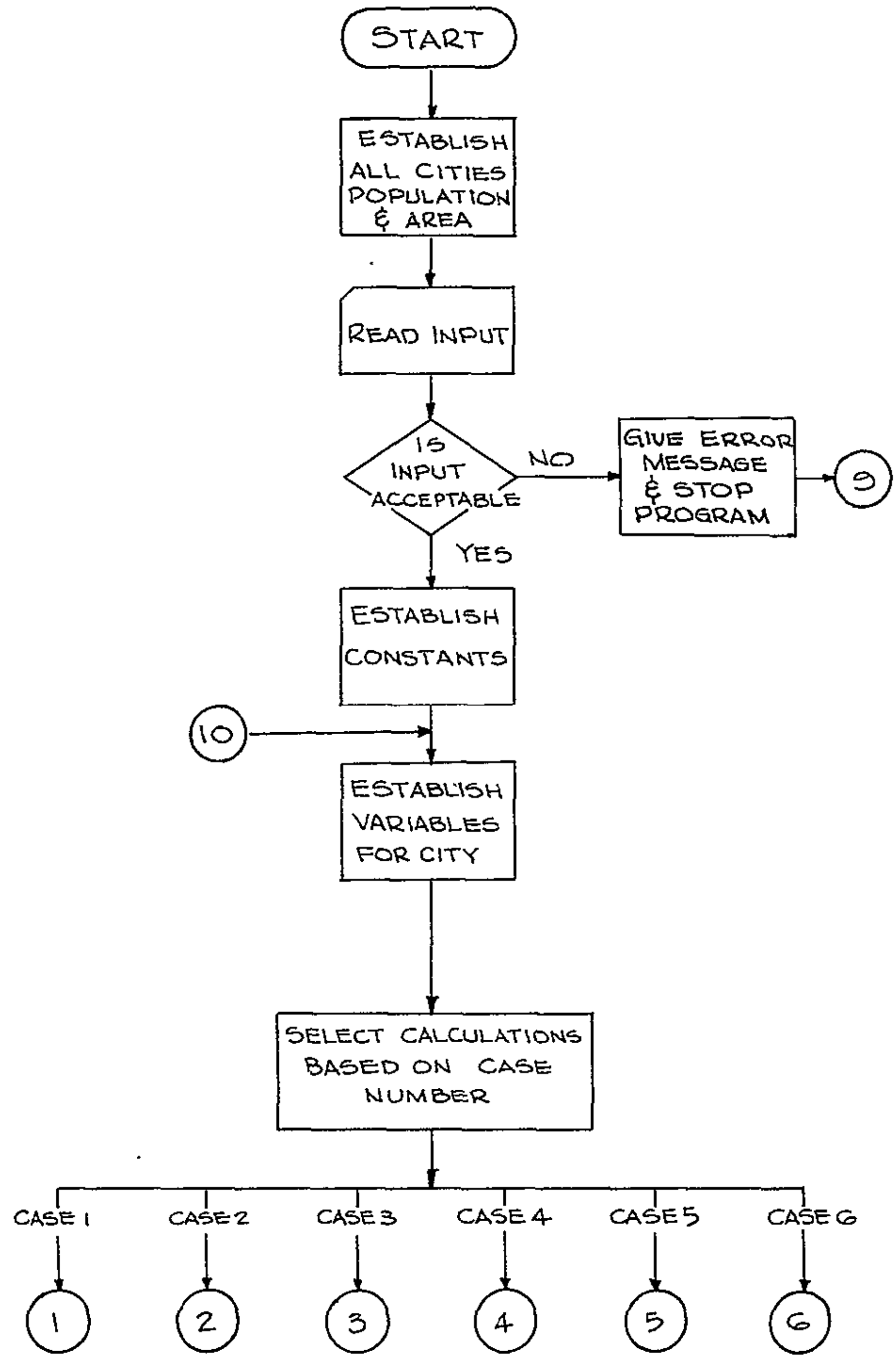


Figure 4.8

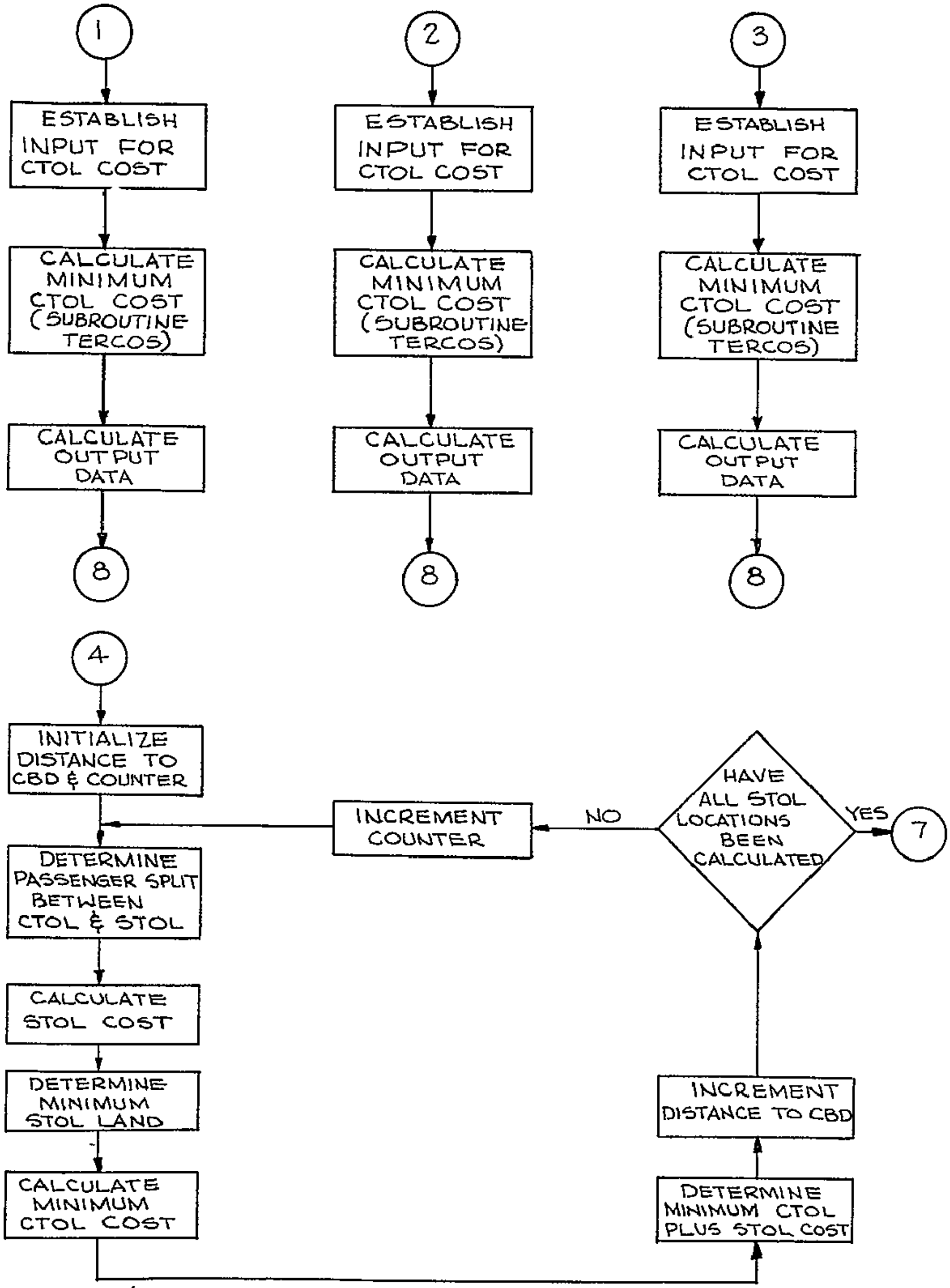


Figure 4.8 continued

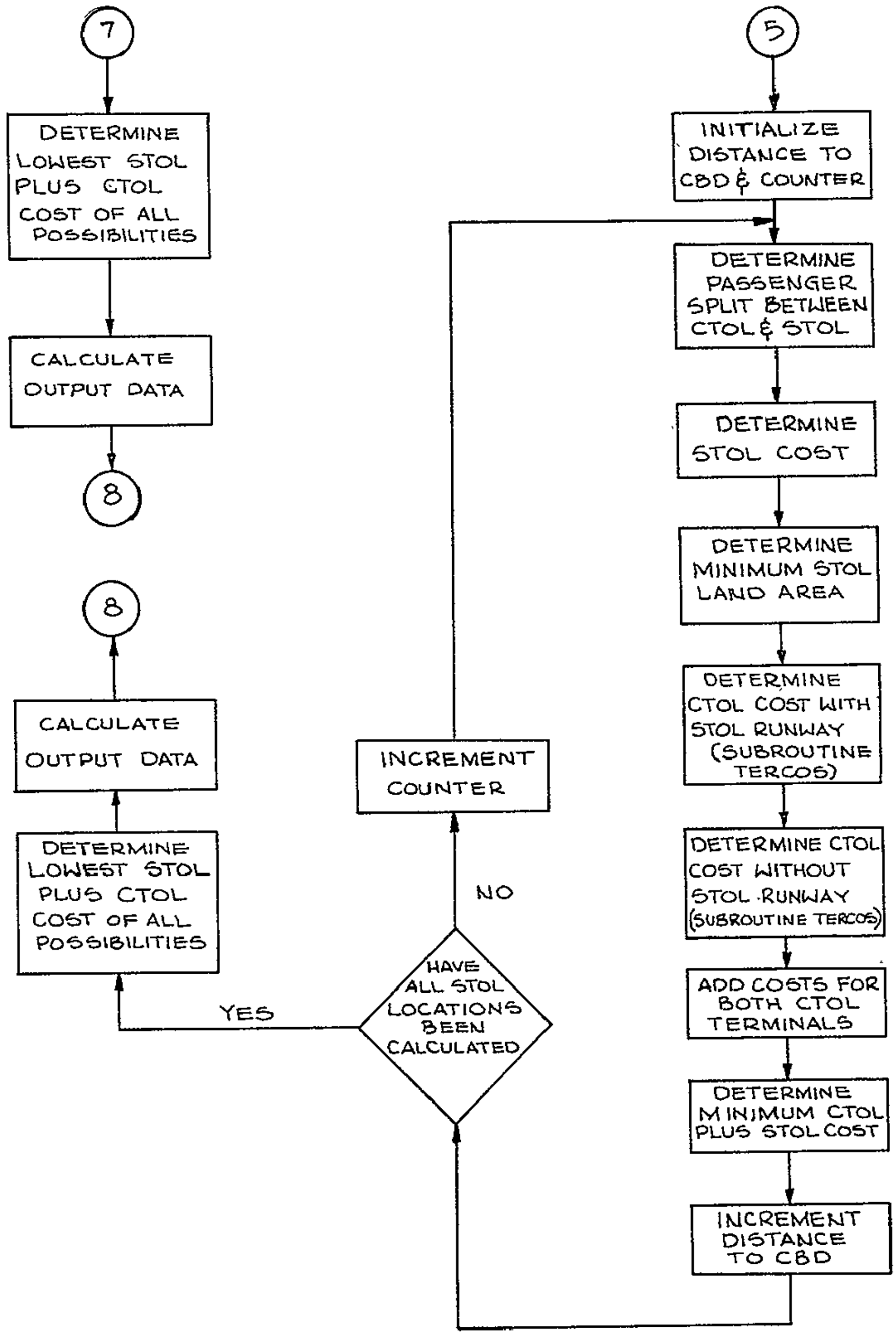


Figure 4.8 continued

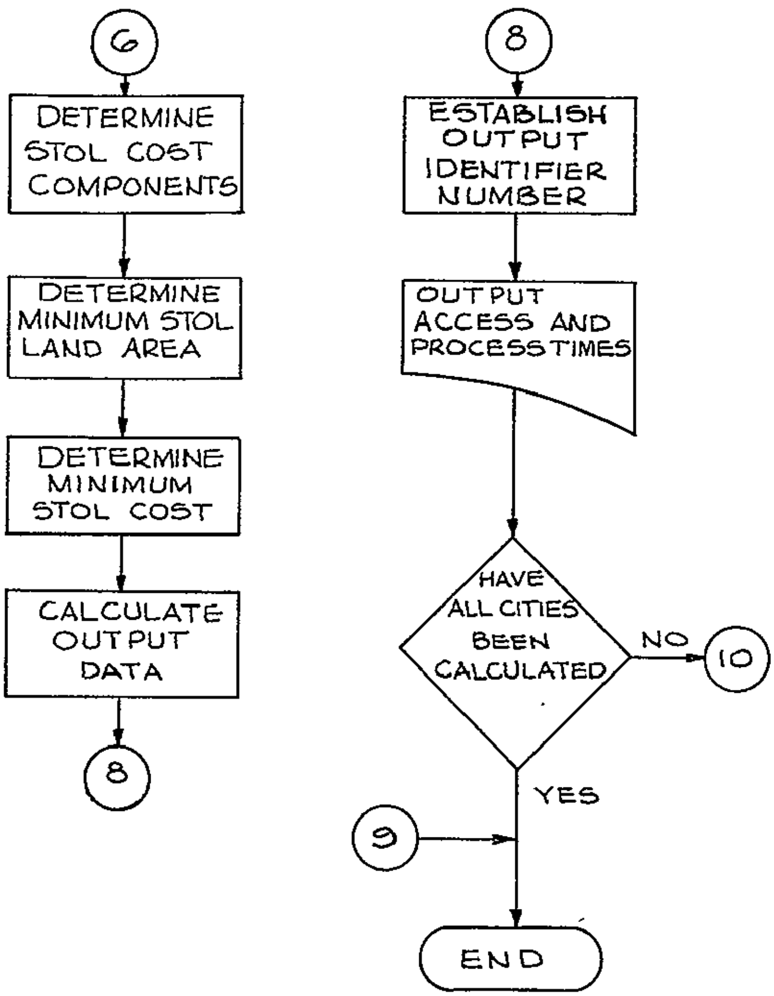


Figure 4.8 continued

CTOL-STOL TERMINAL MODEL

FLOW DIAGRAM CHANGES

COST VERSION

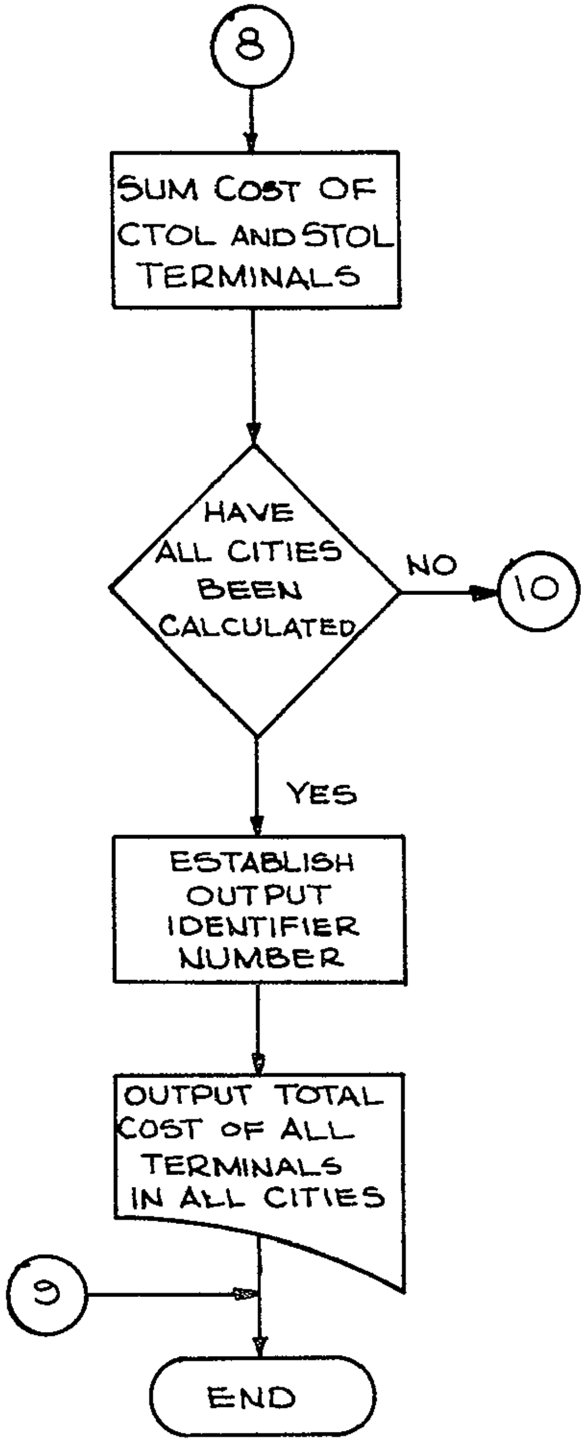


Figure 4.9

model is shown in Appendix 4-D. The changes required for the cost version are shown in Appendix 4-E. It is noted that the program output contains output to both line printer and card punch. The printed output was used to check the output values while the punch card output was used to exchange information between the various other models in the overall system evaluation.

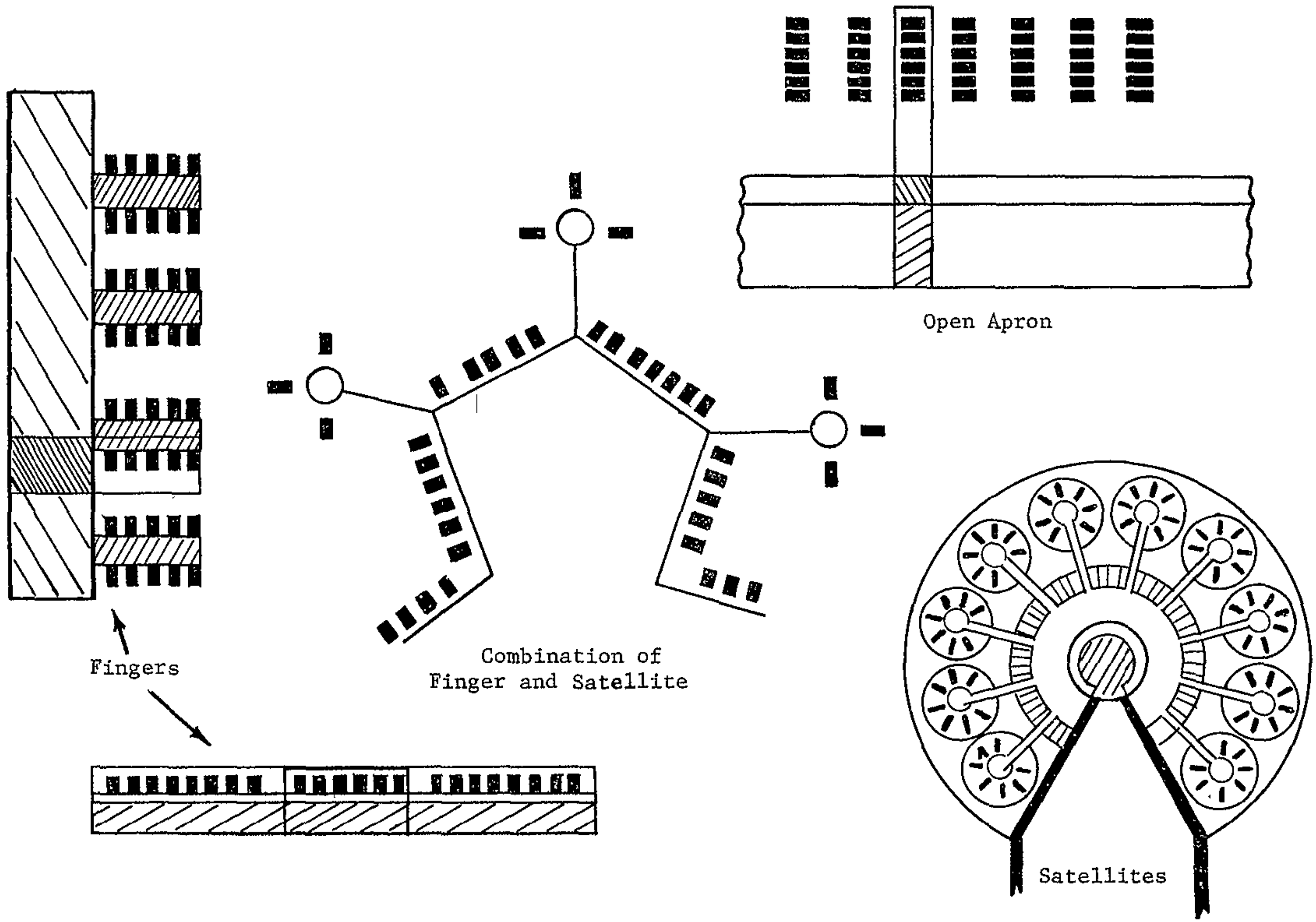
4.4. A Parametric Cost Analysis of Alternate CTOL Terminal Configurations

Rather than consider one or two particular cities of certain populations, and then try to design a specific terminal for each, the following is an attempt to cost three basic terminal configurations according to their specific design requirements and certain uniform assumptions. In a general study as this, it is highly unreasonable to design a terminal or airport for just certain cities. It is far better, considering the situation, to use a general approach that can be applied to most city types.

There are many varieties of terminals that can be placed in three basic classes: Satellite, Finger, and Open Apron (See Figure 4.10). There are many combinations and arrangements of these classes that will provide a modern airport layout for future needs. In the case of the small city there may only exist one configuration, while at the larger city there will probably be a different arrangement for each major airline.

4.4.1 Assumptions

1. Each basic terminal configuration will be considered as a separate and an inherently complete unit.
2. Each unit will contain all the necessary facilities for the following:
    a. Airport access
    b. Parking
    c. All terminal building functions



Various Airport Configurations

Figure 4.10

d. Aircraft parking of gates

e. Aircraft apron

f. Aircraft service facilities.

4.4.2 Design Requirements

1. Each unit will be capable of handling all types of aircraft at each gate position (DC-9, DC-10, DC-8-63, B-707-321, B-747, L-1011, SST and other future aircraft).
2. There will be six gate positions.
3. Aircraft service rate will be limited to 30 minutes per aircraft, independent of type.
4. The average load per aircraft of all types is considered to be 300 passengers per flight. (This implies 3600 typical peak hour passengers (TPHP) per unit terminal).
5. Terminal process time will be constrained to within 25 minutes.
6. Each terminal will employ the necessary systems to reduce waiting times in queues such that the overall process time (parking lot to aircraft or vice-versa) is reduced to within the 25 minutes.
7. Baggage handling system will be capable of sorting and handling 2.5 bags per TPHP on international flights and 1.5 bags per TPHP for domestic flights.

4.4.3 Terminal Building Design Criteria

Samuel Eastman's study of the Comparative Cost and Capacity Estimate of Vertiports and Airports 1975-1985, [3], was used as the basis for determining the basic area requirements for the terminal. He presented estimates of 338 square feet per TPHP (high) and 41 square feet per TPHP (low). On re-examining this data a better conservative figure, when planning for expansion and undoubtable growth of the number of TPHP appears to be 318 square feet TPHP. This number was determined on the following basis:

Terminal Section	Ft^2/TPHP	Area (ft^2) for 3600 TPHP
Ticketing, Reservations and Info.	4.3	15,600
Passenger Check-in and Service	10.0	36,000
Baggage Claim	40.7	146,400
Concessions	36.0	129,600
Eating areas and Kitchens	29.3	105,600
Public Space	138.3	498,500
Passenger Waiting Room	17.7	63,600
Admin. & Bldg. Service (Flightopsede)	41.3	148,800
TERMINAL BUILDING TOTAL	317.6	1,143,900 ft^2

TABLE 4.2

The cost of land was obtained via a formula described in section 4.2.2. If a single runway was considered practical, then the development of a single monolithic structure to contain all of the airport functions was evaluated. This was compared to the more conventional ground level development and the configuration with least cost was used in a particular situation.

By a search procedure, the location in a city which yields the least total cost considering costs of structures, land, access, operations, and maintenance was determined optimal. (See Figure 4.7).

4.4.4 Parking Facilities Design

It has been argued that the American public will depend more heavily upon his automobile than in the past. It has been the general trend to design facilities for the convenience of the passenger and his auto as at Dulles International Airport, Washington, D.C. and at the Pan Am. terminal, JFK, New York.

Looking at the Transportation Engineering Journal for airports, one sees the following:

Percent	Primary mode of arrival or departure from the airport
52	Car
24	Taxi
22	Bus
2	Rail or other

TABLE 4.3

However, when one looks at Cleveland and observes the great success the rail link between the airport and the central business district (CBD) is having, one begins to wonder whether or not it would be better to have a rapid transit (RT) link replace the auto as the primary means to the airport. Mr. Voorhees and associates indicated in a lecture presented to our group in January 1969 that a RT link to the airport, built in a city without an already-established RT system is not feasible. But should such a system already exist as in New York or Cleveland, an extension of the same could prove beneficial if there were considerable savings for the user. The success of the Cleveland RT is eximplified by the cab drivers' complaints of much loss of business.

It has been decided that unless RT already exists, the terminal complex will be designed to accept rubber wheeled ground vehicles at the percentage of table 4.3 for this project. A certain percentage of the passengers and visitors that come by car will desire to park at the airport.

Mr. Eastman pointed out that the FAA survey indicated that airports should have 1.3 parking places per TPHP. The Transportation Engineering Journal shows how these parking places are used:

% of all Parking Spaces	Who Parks There
53	Short-term (0-6 hrs) Passengers and Visitors
7	Long-term Passengers (24 hr. or longer)
40	Employees

TABLE 4.4

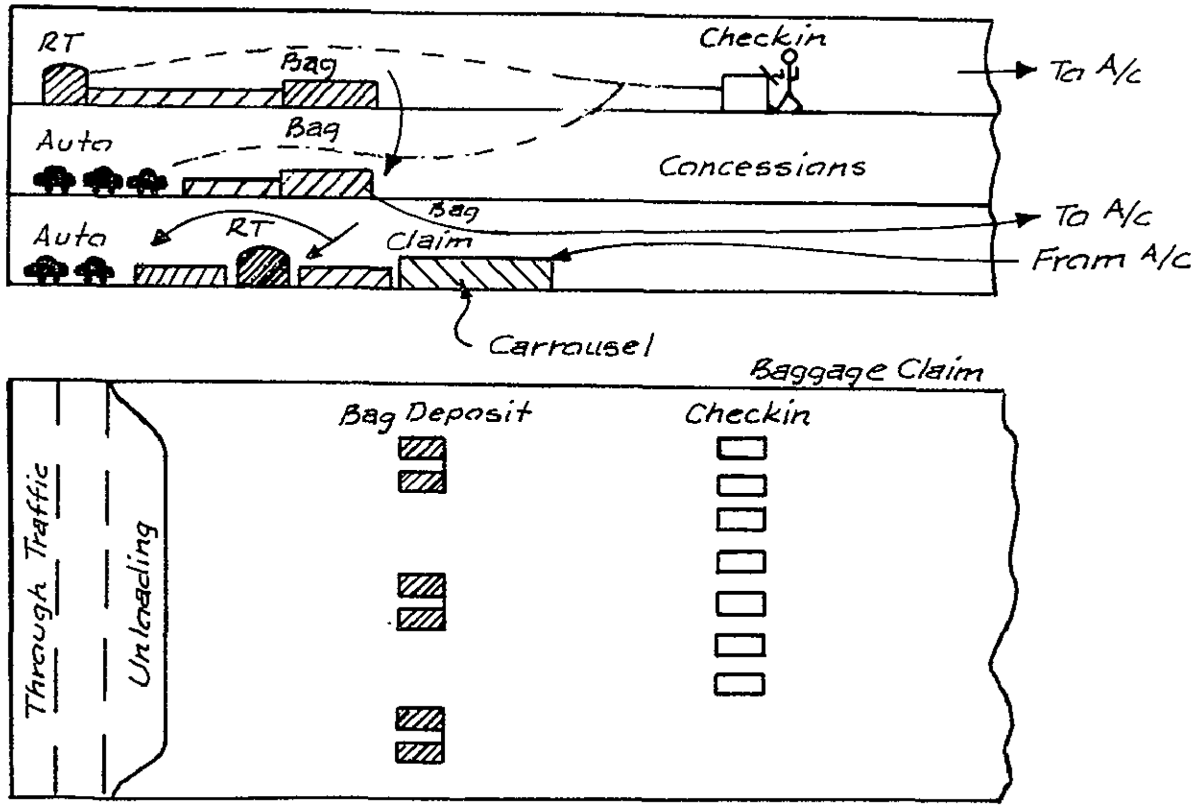
Parking structures can only be justified if the land values are high enough as in the Chicago or New York area. The only terminal unit to use multilayer parking will be the satellite terminal and it will be at the hub and in only three layers. The other configurations will use one level parking and/or roof parking.

4.4.5 Passenger Convenience Design

Each terminal unit will employ devices to reduce passenger process (i.e. airport ground) time to within 25 minutes. This process time does not include the waiting time of early arrivals. To date most of the terminal designs have the tendency to centralize terminal activities and operations, that is passengers and baggage enter one area and then are dispersed to several other areas as at Dulles or Tampa International Airports. Recently new innovations such as Pan Am's New York terminal, provide for more flixibility and decentralization. The Pan Am terminal, designed for the car and bus allows the passengers to disperse

and sort their own bags as they arrive at their gate. When RT becomes feasible it can be made to let passengers and visitors off directly in front of their aircraft or at the main gate should he be a standby or have to make reservations, etc. As there is today, an interline transportation source can be used to serve the transfer passenger. It has even been suggested that if the RT link exists then the airlines should purchase several RT vehicles (which could be designed to reflect the corporate image). Of course, these vehicles would provide direct service to the terminal from the CBD or another downtown station. The vehicles can be both steel and rubber wheeled for versatility. Since such a system does not exist now, it would be rather difficult to determine its cost.

Figure 4.11 shows how both RT and the auto might interface with the aircraft at the gate or at the main terminal.



Modal Interface

Figure 4.11

4.4.6 Assumed Unloading Times

The following times have been assumed to unload passengers and baggage from the following vehicles:

Vehicle	Unloading time (mins.)
Car	2.0
Taxi	1.5
Bus	5.0
RT Vehicle	3.0

TABLE 4.5

4.4.7 Other Airport Facilities

The cost model developed in the Appendix 4-F will not include the costing of various facilities considered standard with any airport design of reasonable size. These include:

a. Underground fuel storage and pumping units to serve 0.6 aircraft per unit terminal.

b. Aircraft service vehicle for the same.

c. Electric power consumption.

d. Landscaping, etc.

4.4.8 Unit Terminal Description

Cross-hatch code for figures:

- terminal building

- parking lot

- access route

- gate or aircraft parking

- apron area

- service vehicle parking (satellite unit only)

Blank - excess area not included in terminal complex

4.4.9 <u>Satellite Terminal Sector</u>

In approximately a 36° sector of a radius of about 3,400 ft., all the required area noted in section 4.4.12 can be contained if there is a two story terminal building and a three level parking structure. It has a geometric shape factor (GSF) of 1.083 and a parking ratio (PR) of 5.38. Note that GSF is defined as all the necessary terminal complex. PR is the total apron area plus gate area ÷ gate area. (See Figure 4.12).

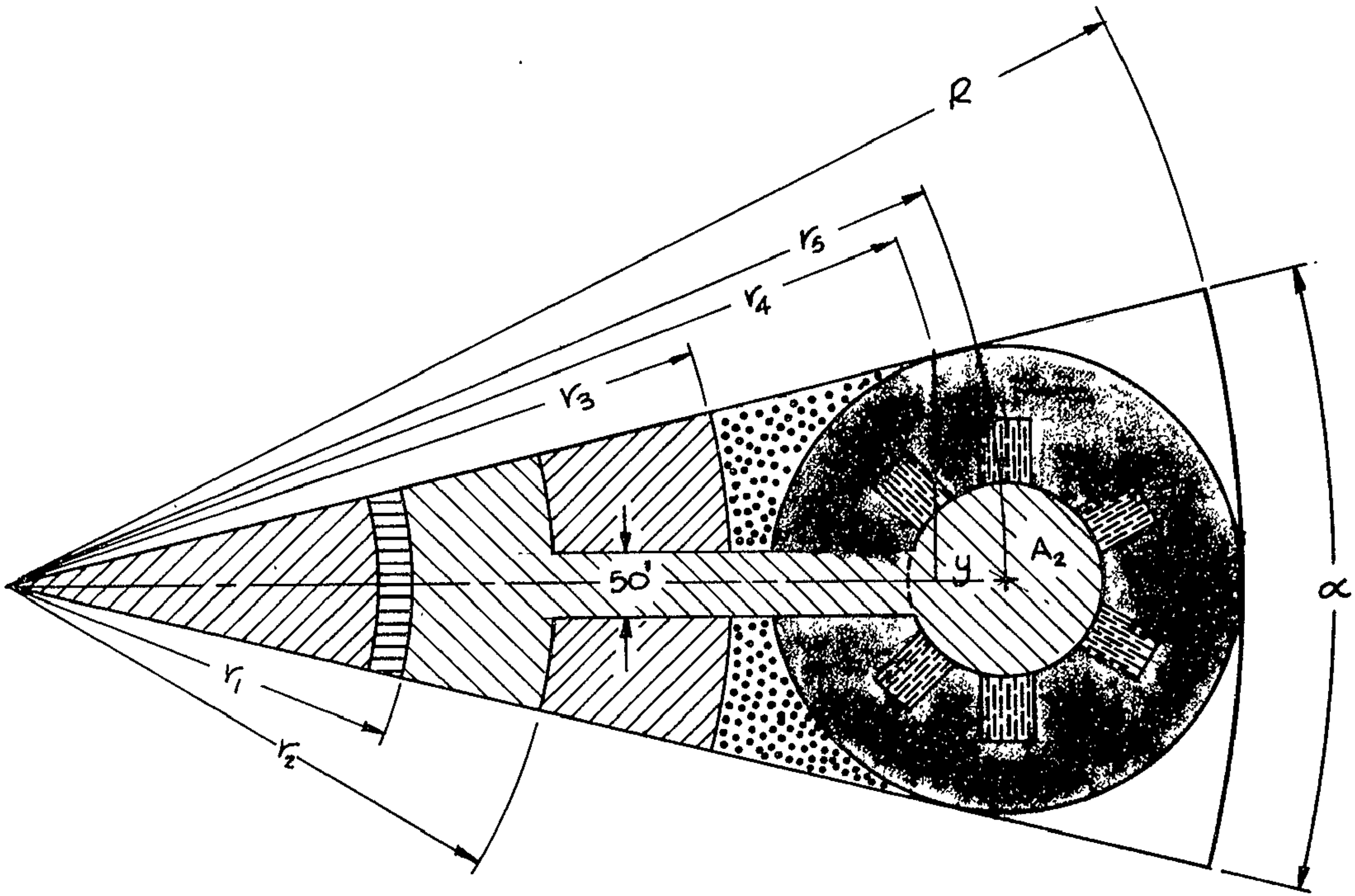
Aircraft nose-in parking allows for the minimum area required and yields a small PR and GSF.

4.4.10 <u>Finger Units</u>

For parallel nose-in parking a 200' x 300' gate or parking area is required to accommodate any type aircraft. A 30 ft. separation between areas has been assumed. Aircraft manuvering room has been assumed to be a 350 ft. diameter circle based on a one-wheel-stand-pivot. Using some imagination and considering the amount of capital available and runway layout, these finger units may be stacked in almost any desirable configuration or may be combined with any of the other two basic units.

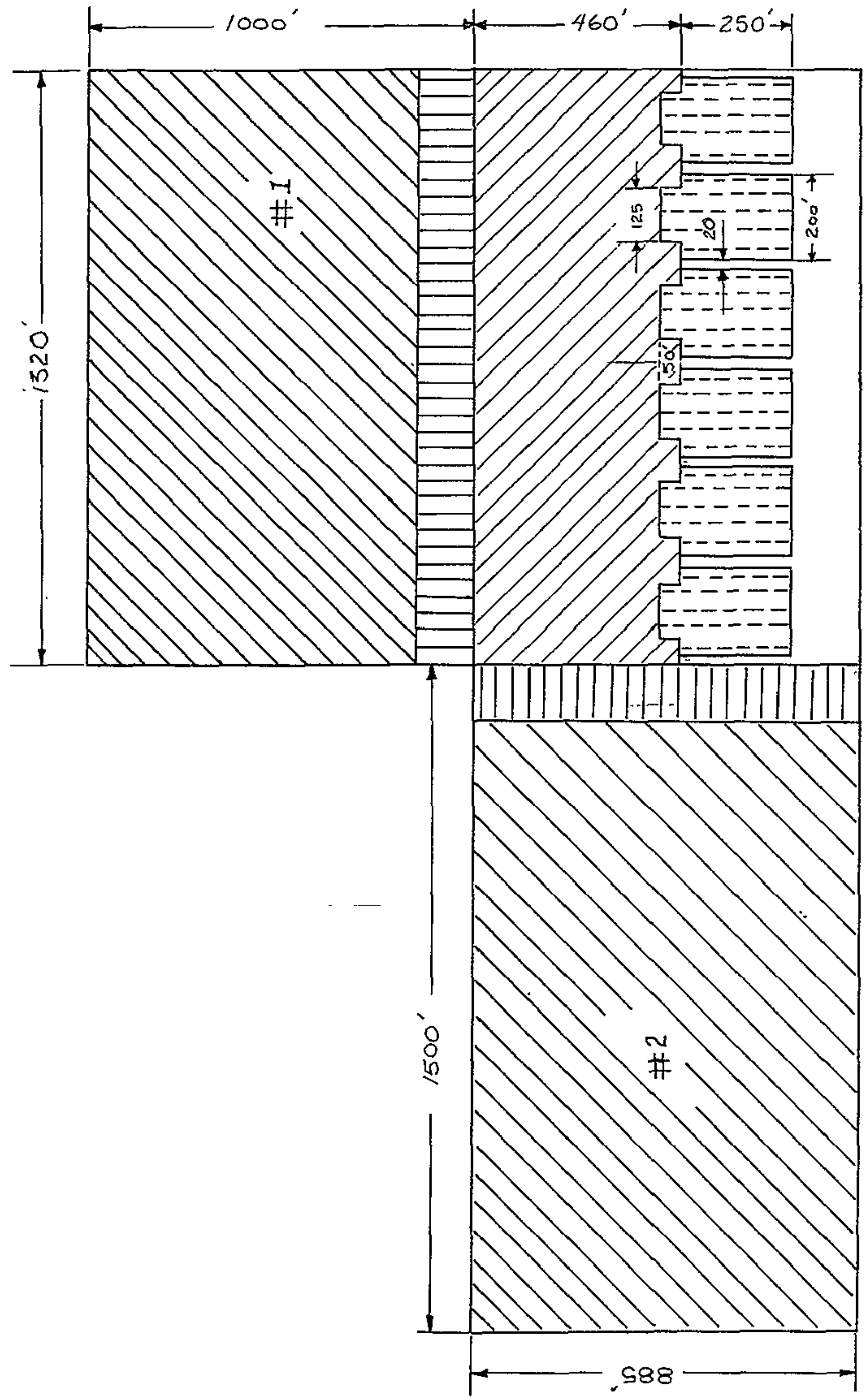
Finger design I will be a two story structure while that of II will have a 3 floor main building and two story wing. (Figure 4.13 and 4.14).

Parking is shown as ground level in all units except the satellite unit, however, should land prices warrant, parking structures would be considered.



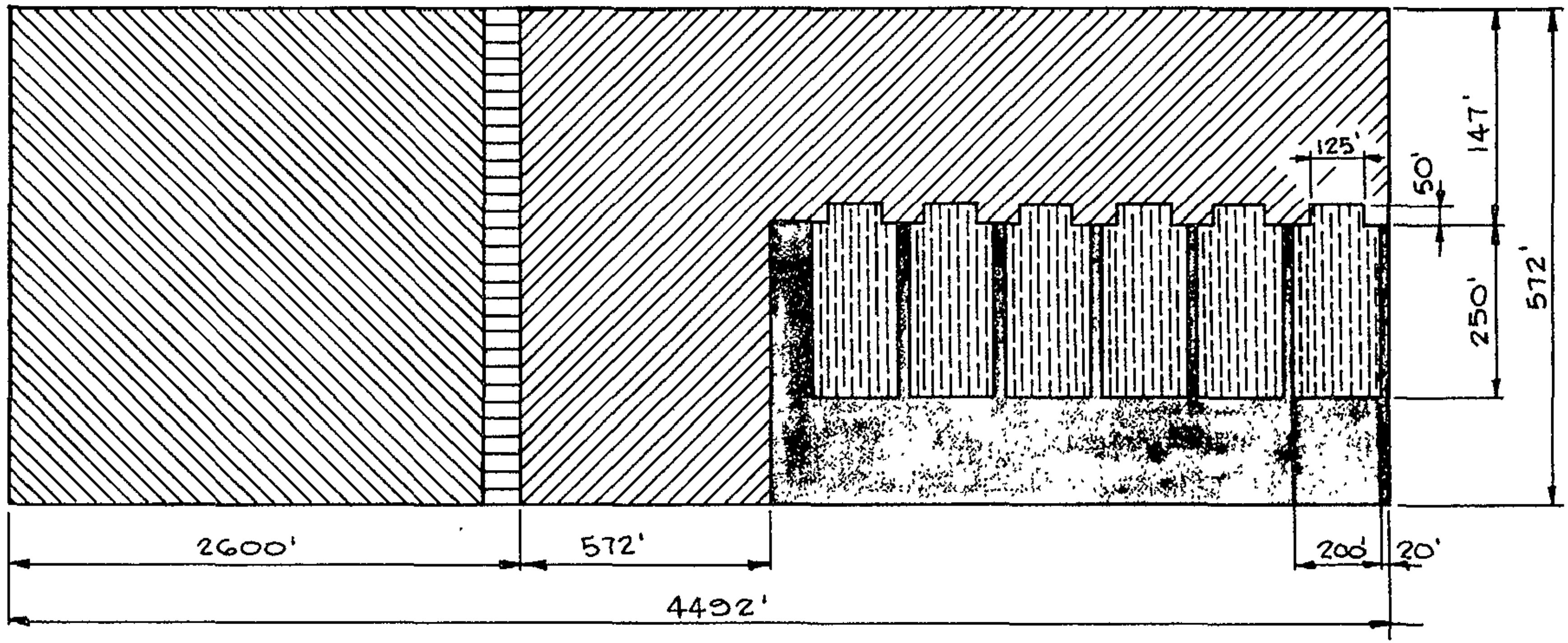
SATELLITE TERMINAL SECTOR

Figure 4.12



Finger Unit I (with parking #1 or #2)

Figure 4.13



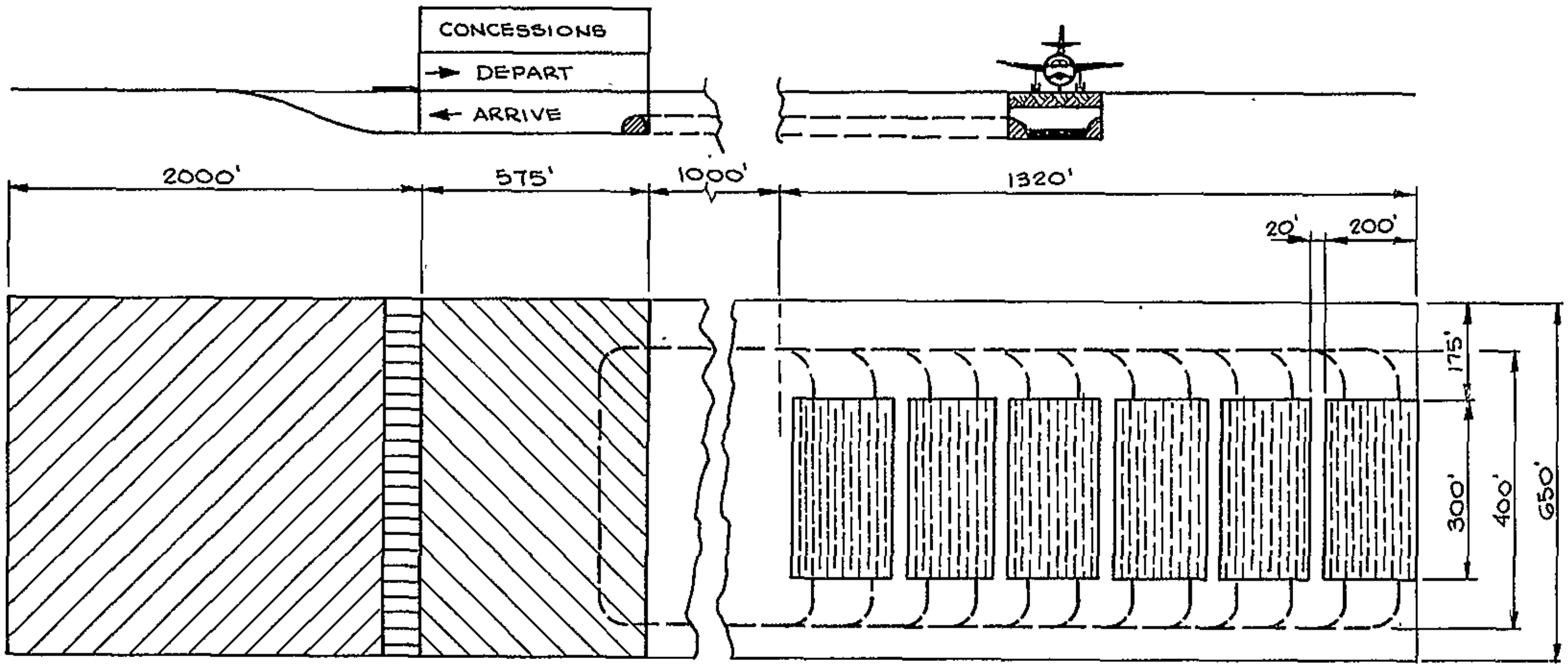
Finger Terminal II

Figure 4.14

4.4.11 <u>Open Apron</u>

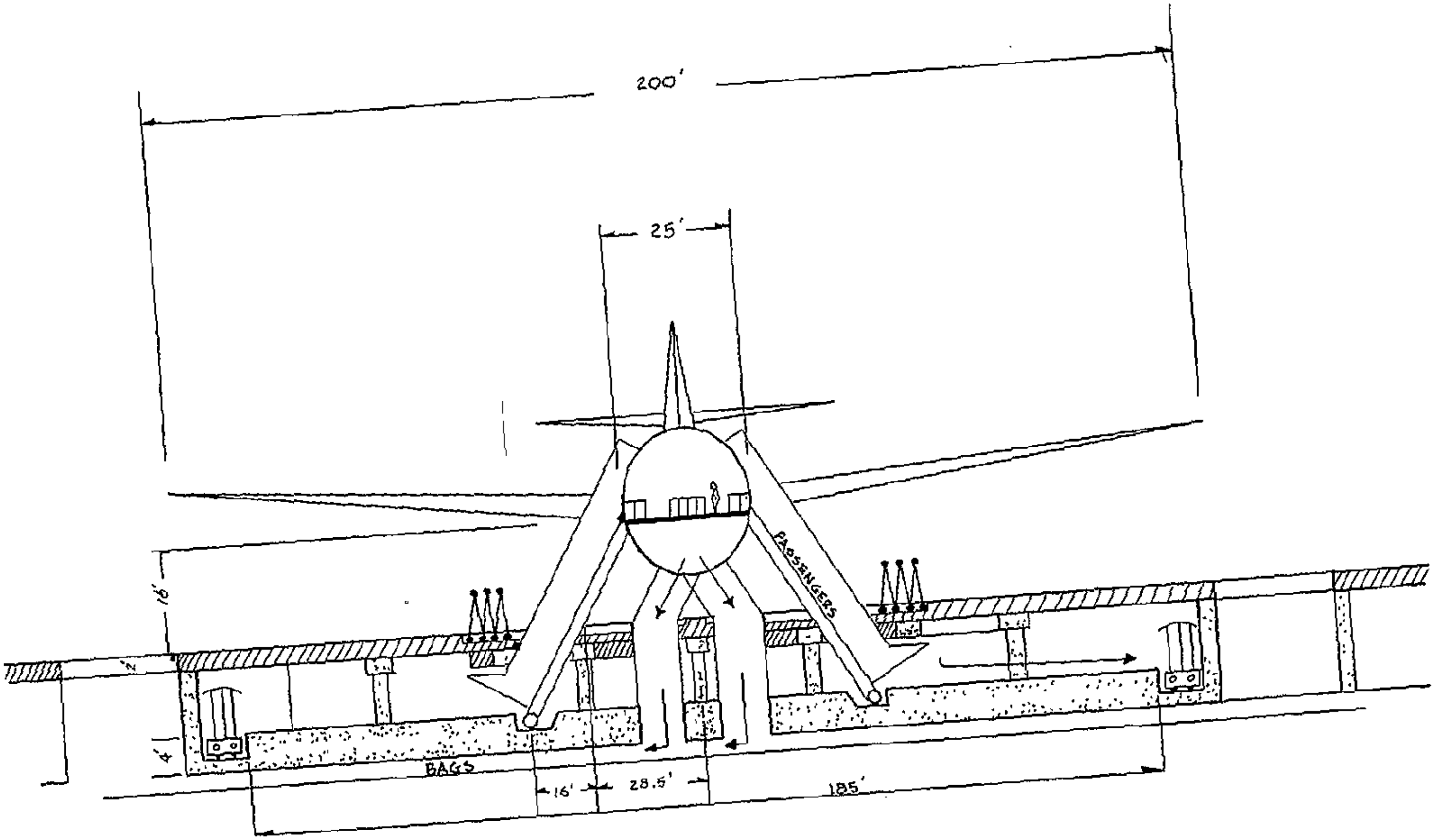
This design is mainly for the airline's convenience. For the passengers convenience a fast and efficient transportation system must be employed to move passengers and baggage to and from the aircraft. With this system the airline pilot, soon after landing, brings the aircraft to a stop at one of marked gate positions and the aircraft service crews begin operations on the aircraft. When completed, the aircraft simply departs with ground clearance (Figure 4.15). It eliminates all the excess cost associated with the long taxi from the runway, and the manuvering and pushout procedures. Generally, it is cheaper to transport baggage passengers, etc. by other means than the aircraft. The open apron developed here employs an underground transportation system and a three floor terminal building. This eliminates the above ground confusion and obstacles for the aircraft. With more time this system should be compared with the hazards and costs of above ground transportation (Figure 4.16).

The underground system will use electric-rail vehicles (6' x 10') and carrying 15 standing people at 15 mph. All 6 aircraft of 300 passengers each will be filled in 10 minutes by a minimum of 2 cars per A/C each minute. Baggage and mail is handled on a separate conveyor system (Figure 4.17).



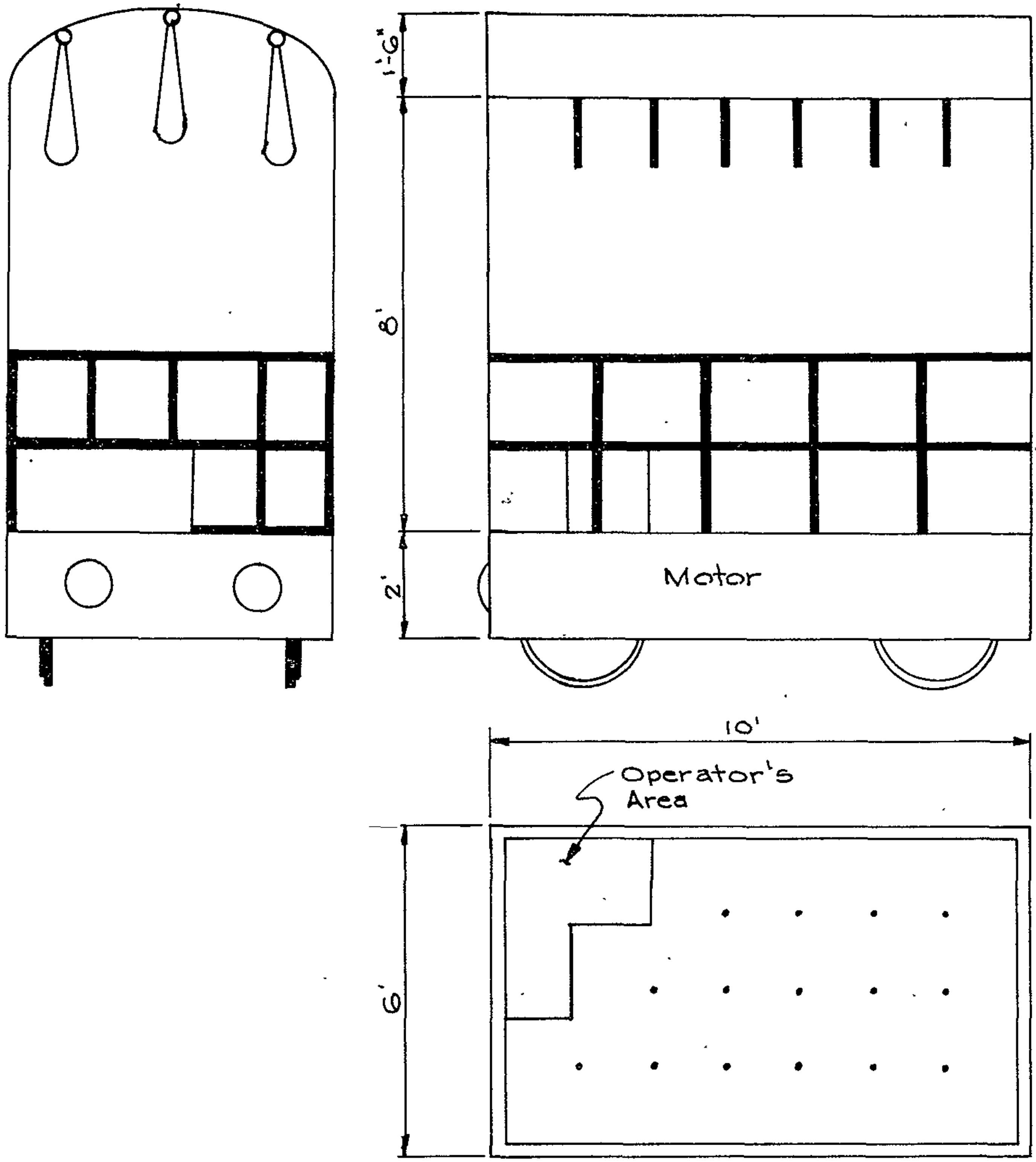
OPEN APRON UNIT

Figure 4.15



Subterranean Station

Figure 4.16



ELECTRIC CAR

Figure 4.17

4.4.12 Summary of Data on Basic Unit Terminal

A summary of data on basic unit terminal configurations is shown in the following table:

TABLE 4.6

Parameter	Terminal Unit			
	Sattelite	Finger		Open Apron
Terminal area	1,143,900 ft^2	Same		Same
Parking area	1,310,400 ft^2	Same		Same
Access Roads and Extra Land	338,680 ft^2	Same		Same
		I	II	
GSF	1.083	1	1	1
PR	5.38	1.87	1.56	4.19
f	.5	.5	.5	.5
LB	11,054 ft.	8,640	7,344	7,580
LT	-	-	-	7,520 ft.
DT	-	-	-	5 ft.

Note: Appendix 4-F has a detailed explanation of specific costs related to these terminals.

4.5 Terminal Subsystems

4.5.1 Introduction

Due to increased demand, many operations which are carried out manually today will have to be automated, or existing procedures optimized, in order to decrease process time or to reduce operating costs. It is imperative that some priority for automation or optimization of operations be established so

that invested capital will produce maximum benefits in reduced delays or costs. Priority operations should be investigated to determine what improvements are feasible and, if necessary, the automated systems should be designed.

4.5.2 Subsystem Improvement Priorities

On first priority are those subsystems which must be automated in order to process the increased demand of the target period. The reservation and ticketing system fell into this category years ago and will, of course, remain there. The baggage handling system, which is largely manual today, will necessarily be automated at major terminals in the future. It deserves the greatest developmental effort.

Those systems which may be automated or optimized to reduce delays or operating costs or to increase passenger convenience are of two economic categories. The first category includes those subsystems which can be improved with no additional capital investment. An example is the optimization of terminal layout to reduce walking distance. All systems in this category should be optimized without question during design. The second economic category includes all subsystems which require additional capital expenditures for automation or optimization. Priorities within this group must be carefully established.

In considering automation or optimization to reduce operating costs, the total cost of operating the existing system must be compared to the operating cost plus the capital recovery necessary to amortize the additional investment. If the total operating cost plus capital recovery of the improved system is less than that of the unimproved system, the system is a candidate for improvement.

In the air transportation system there are two major components which, when delayed, render the system less effective. These components are the

passengers and the aircraft. In establishing priorities for subsystem improvement it is necessary to determine which subsystems generate the greatest delay for passengers and/or aircraft.

The Critical Path Method is an established procedure for listing operations in order of inter-dependence and for determining which operations cannot be delayed without delaying the entire system. Such crucial operations are said to be on the "Critical Path."

In order to determine priorities for subsystem improvement, critical path analysis of processes involving passengers and aircraft must be made. Those operations on the critical path are candidates for improvement. If by optimization or automation the critical path is shortened to the extent that another group of operations becomes critical, they too become candidates for improvement.

When all the candidate operations have been identified each must be investigated to determine what the improvements will cost and how much time or money they will save. That combination of improvements which renders the system most cost-effective should be implemented.

Appendix 4-G contains the critical path analyses which led to the following subsystem priorities:

<u>Aircraft Related Delays</u> (based on L1101-385)

Turnaround Station	Intermediate Stop
(1) Cabin Cleaning	(1) Unloading Baggage
(2) Turnaround Maintenance	(2) Loading Baggage
(3) Refueling	

Passenger Related Delays

Departing Passenger	Arriving Passenger
(1) Baggage transport to aircraft	(1) Baggage transport to terminal
(2) Check-in waiting line	(2) Baggage claim
(3) Walking time	(3) Walking time
(4) Ground transport from origin	(4) Ground transport to destination
(5) Gate process waiting line	

It is interesting to note that if the cabin cleaning operation for the L1011-385 were reduced six minutes a saving in aircraft delay time of 19.4% could be realized. This could be done without improving any other operation related to turnaround processing. If in fact it is not possible to improve the cabin cleaning operation, investment in improving any other operation related to turnaround processing for the L1011-385 would be wasted. This is true since the critical path length would remain constant (It is assumed that other than passenger loading and unloading times and the ramp installation and removal times, the only other operations on the critical path, are fixed by the aircraft geometry.)

4.5.3 Baggage Handling System

4.5.3.1 Introduction

The present system of baggage handling will not be economically feasible at terminals in 1980. In that year 372 peak hour operations are expected at the New York terminal. If sixty passengers were exchanged per operation and if each passenger checks 2.5 bags, 55,800 pieces of luggage must be processed per hour at peak hour. Each piece must be handled four times (tagging, sorting, loading trailers, loading aircraft). If all of these jobs could be

done at the rate of eight bags per minute, 465 employees would be required for baggage handling alone. Thus this inefficient and inconvenient system would cost roughly $930 per hour for salaries!

4.5.3.2 The Future System

The baggage handling system of the future must, like the whole air transportation system, be faster, more convenient, and less expensive to operate. Speed and convenience require a system which unburdens the traveler of his luggage at the earliest possible moment and at points numerous enough to hold waiting lines at a minimum. These requirements, coupled with high demand and the need for low operating costs, make automation mandatory. The degree of automation required at a given terminal will depend on peak hour demand, the types of air vehicles used, available ground conveyances and terminal layout. The degree of automation which renders the system most effective should be implemented.

In the fully automated system a departing passenger would, on arrival at the terminal, check his bags at one of many check-in points near all ground transportation. There the bags would be placed in a tote marked in binary and/or alpha-numeric code to indicate air mode or terminal quadrant, gate, pad, flight, destination, and the passenger's socialsecurity number. Also at this time, reservations would be checked and billing initiated. The passenger, unburdened of his luggage, would continue to the main terminal. The baggage would proceed through a sorting process and would, on arrival at the proper pad, be stored until the correct flight was ready for departure. At the proper time the luggage would continue via conveyor directly into the aircraft.

Upon arrival at the destination, luggage would exit the aircraft on conveyors and enter the terminal building where it would be sorted by ground mode and sent to pickup points near the proper ground conveyance. Thus a

passenger leaving the terminal via taxi would reclaim his luggage at the taxi stand.

The system for private automobiles is somewhat more complicated. The baggage from the ground-mode sorter would enter a storage area which consists of a large number of storage cells. The matrix would also be represented in the terminal's central computer. As a tote is placed in a storage cell, the social security number corresponding to the luggage is fed to the computer. The passenger then has only to signal for his luggage at the pickup point nearest his car. At this signal, the computer would search it's matrix for the correct social security number and demand the automatic picker to eject the luggage to the delivery conveyor. A coding machine would also mark the tote for the correct pickup point and, after a sorting process, the luggage would be conveyed to the passenger.

4.3.3 The Baggage Handling-System Cost Model

This system is obviously new and untried. Therefore, cost models are impossible to construct without at least preliminary design. Due to time limitations, the preliminary design is at best sketchy, and alternate designs for subsystems have not been considered. The cost model is therefore necessarily approximate. The objective is to demonstrate the technical and economic feasibility of the system and to provide enough data to allow gross cost effective analysis. Appendix 4-G contains the preliminary design from which the cost model was derived.

4.5.4 Aircraft Related Subsystem Improvements

The baggage handling system of section 4.5.3 will greatly reduce the delays associated with baggage claim or distribution. The waiting times can be minimized by providing enough ticket agents and check in points. The number required for a given demand can be predicted by queuing theory.

The walking times have been minimized in the terminal layout and the location of the STOL ports were made to minimize ground mode travel time.

4.6 Ground Access Modes

The study of ground facilities also included urban travel characteristics, trips to and from the congested Central Business District, costs of intra-city travel, and how these specifically bear on the airport.

4.6.1 Urban Travel Characteristics

In measuring the effectiveness of the proposed system, cost and travel time are of major consideration. The cost and time involved is not only that of air fare and air travel time, but the expense, both in time and money of getting to the airport. Therefore, research was undertaken to determine both of these parameters for varying size urban areas. For analysis purposes, the trip to the airport was segmented into two parts; the trip from origin to the central business district and the trip from the central business district (CBD) to the airport. The following discussion is concerned only with the former. First, the number of daily trips to the central business district is presented, then trip time and cost, and finally, the model split or the percent traveling to the central business district by auto and other forms of transit.

4.6.1.1 Daily Trips to the Central Business District

When the possibility of a downtown STOL-port is present, an important factor to consider will be the number of people who travel to the central business district during an average day.

A number of factors will contribute to trip generation by the central business district; the most important will be facilities available in the central business district (i.e. employment, shopping, facilities, etc.), configuration

of the urban street pattern, available travel modes, and location of the central business district.

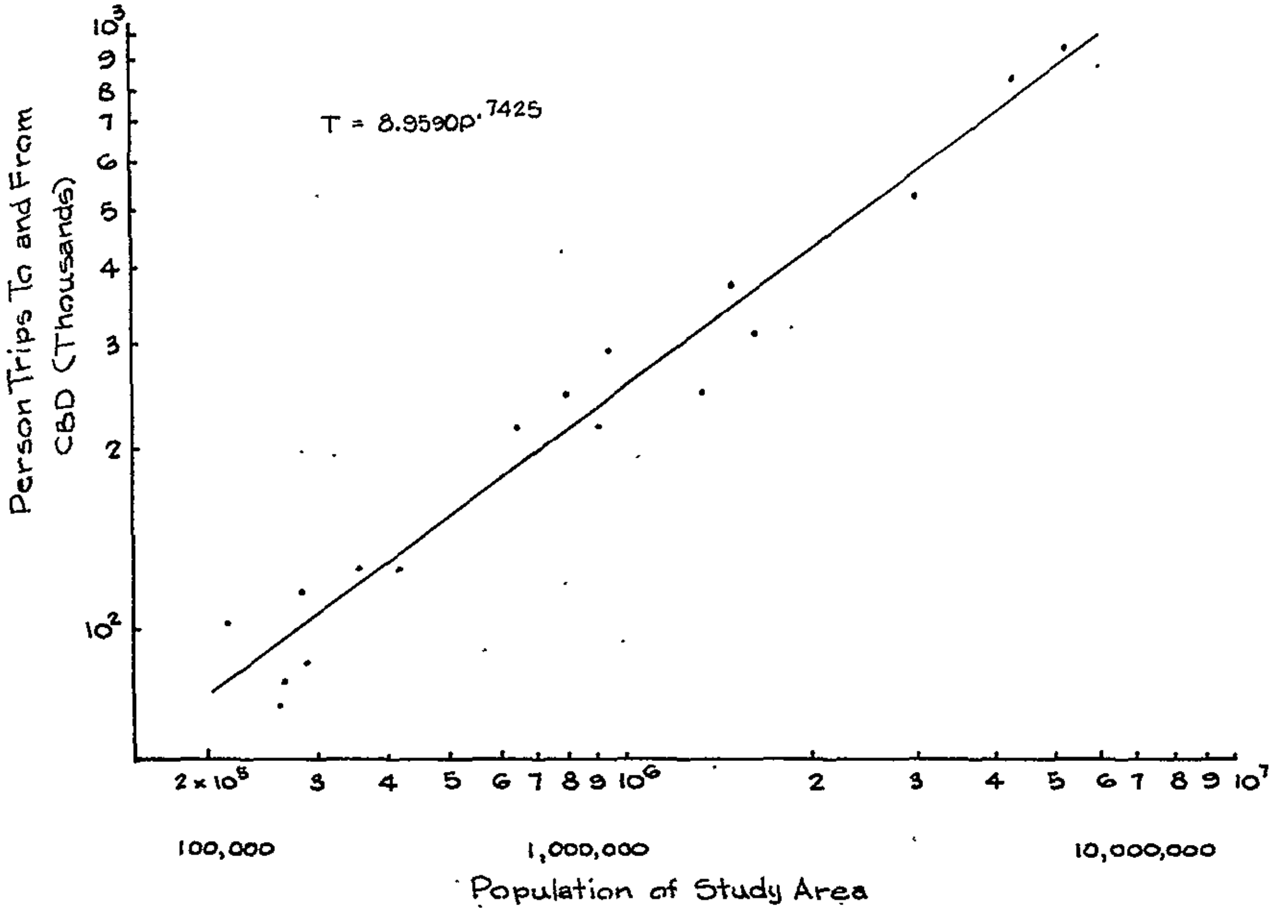
The magnitude of these trips can be readily determined from the origin and destination studies that are part of every transportation plan. Such data has been taken from a number of studies in cities of varying sizes; the number of person trips to and from the CBD was then plotted against population. This is shown in Figure 4.18, Central Business District Trip Generation.

As would be expected, trips to the central business district increase as population increases. We should keep in mind, however, that within the indicated ranges, trips to and from the central business district versus population give a straight line relationship on a log-log scale. This would suggest a decreasing rate of trip attraction with increasing population.

This finding is borne out when trips to the central business are considered as a percentage of total urban trips. When this data is plotted against population size, Figure 4.19, we see that trips to the central business district decrease as a percentage of total urban trips with increasing population.

4.6.1.2 Urban Travel Time

Investigation of various origin and destination studies, speed and delay studies, and transit studies, throughout urban areas in the limited states yielded data on average urban travel time. This time was analyzed on both automobile and other transit travel in regard to various groupings or urbanized area population. The results are presented in Table 4.7.



CENTRAL BUSINESS DISTRICT TRIP GENERATION

Source: Wilbur Smith, Various Traffic Reports [6]

Figure 4.18

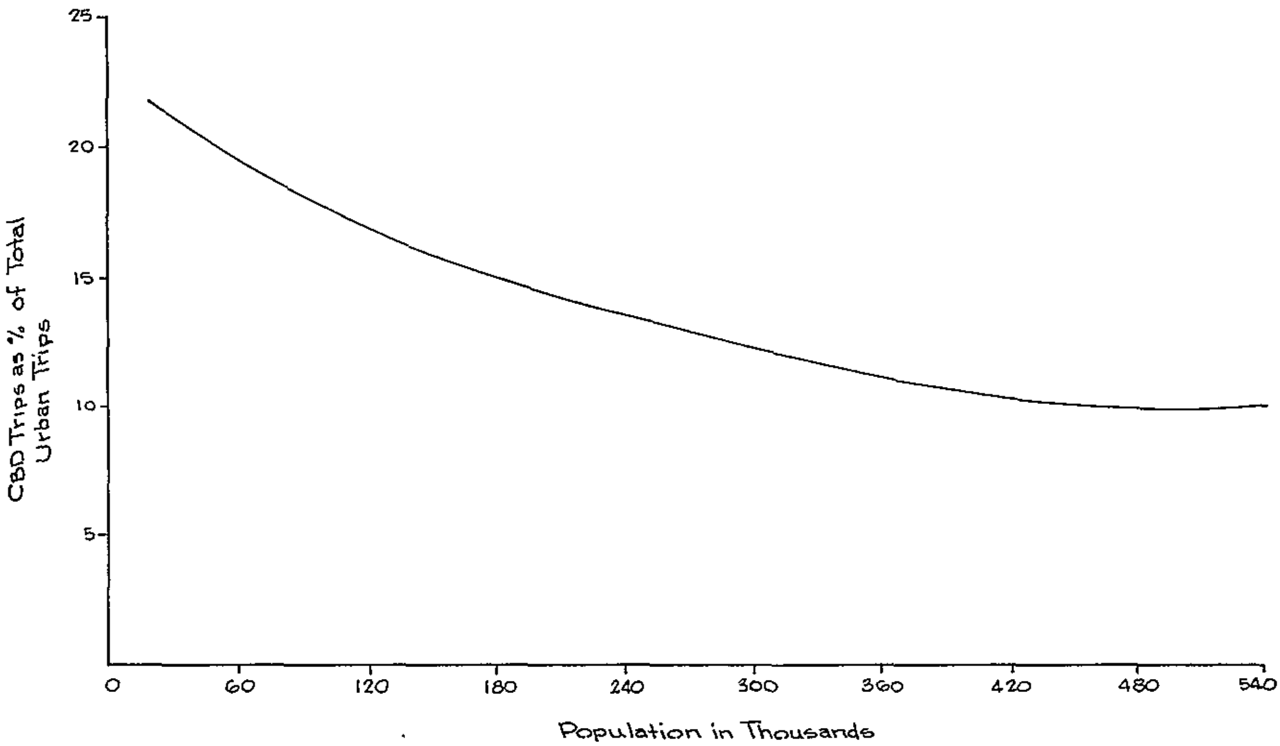
Comparative Urban Trip Times

In Relation to Urban Population

Urbanized area Population	Mean Trip Time (min.)	
	Auto	Transit
100,000 or less	8	15
0.1 - 0.5 million	11	20
0.5 - 1.0 million	16	30
1.0 - 5.0 million	22	40
over 5.0 million	30	60

TABLE 4.7

Source: (Estimated) Wilbur Smith [6]



CBD Trips as a Percentage of Total Urban Trips, by City Population. [6]

Figure 4.19

As can be expected travel time is greater in larger cities and longer by transit.

The travel time shown is portal-to-portal time. In the case of the automobile this type includes walking from the parking area to the destination. The trip time for transit includes the time for getting to the station, waiting time and time from the station to the destination.

4.6.1.3 Modal Split

The final step in determining the cost and time of travel to the central business district is to determine the number of people that travel by automobile versus transit. This is called the modal split.

Transportation studies of varying size cities were accumulated and urban population was compared to percent of auto and transit trips to the CBD. This data is shown in Table 4.8 and plotted on Figure 4.20.

A simi-log relationship was assumed and a curve fit to the data. The equation for the curve is $T = 363.38-51.82 \log P$ where P = urbanized area population; T = percent of CBD trips by auto.

Generally as the population decreases the percent of automobile trips to the central business district decreases, and thus, percent of transit feasibilities in some cities by 1980 may slightly alter this curve, however, it should be tempered by the universal growth of automobile use.

4.6.2 Urban Trip Costs by Travel Mode

Costs equations have been developed to predict the cost of a trip by transit or by automobile (for 1966 values).

Two such equations with approximate values are:

Transit -

Transit Cost: $F + K\,(t_2 + 60\ \frac{d_1}{V_2})$

F = one-way fare = \$0.25

t_2 = walking, waiting, and transfer time = 7 min.

V_2 = speed - 10 mph

K = time cost per minute = \$0.02

d_1 = trip length in miles

Modal Split - 1966

City	Urban Pop. (1960)	Percent CBD Trips by: Auto	Transit
Los Angeles	(2,479,015)	45.5	54.5
Chicago	(3,550,404)	29.0	71.0
Philadelphia	(2,002,512)	41.4	58.6
Detroit	(1,670,114)	56.2	43.8
Boston	(697,197)	40.0	60.0
Washington	(763,956)	55.0	45.0
Pittsburgh	(504,332)	49.1	50.9
Minneapolis	(482,872)	73.2	26.8
St. Louis	(750,026)	53.1	46.9
Houston	(930,219)	69.2	30.8
Kansas City	(475,539)	69.6	30.4
Phoenix	(439,170)	89.3	10.7
Nashville	(170,874)	79.4	20.6
Chattanooga	(130,009)	83.8	16.2
Charlotte	(201,504)	85.9	14.1
Tucson	(212,992)	82.1	17.9

TABLE 4.8

Source: Wilbur Smith, Various Transportation Studies [6].

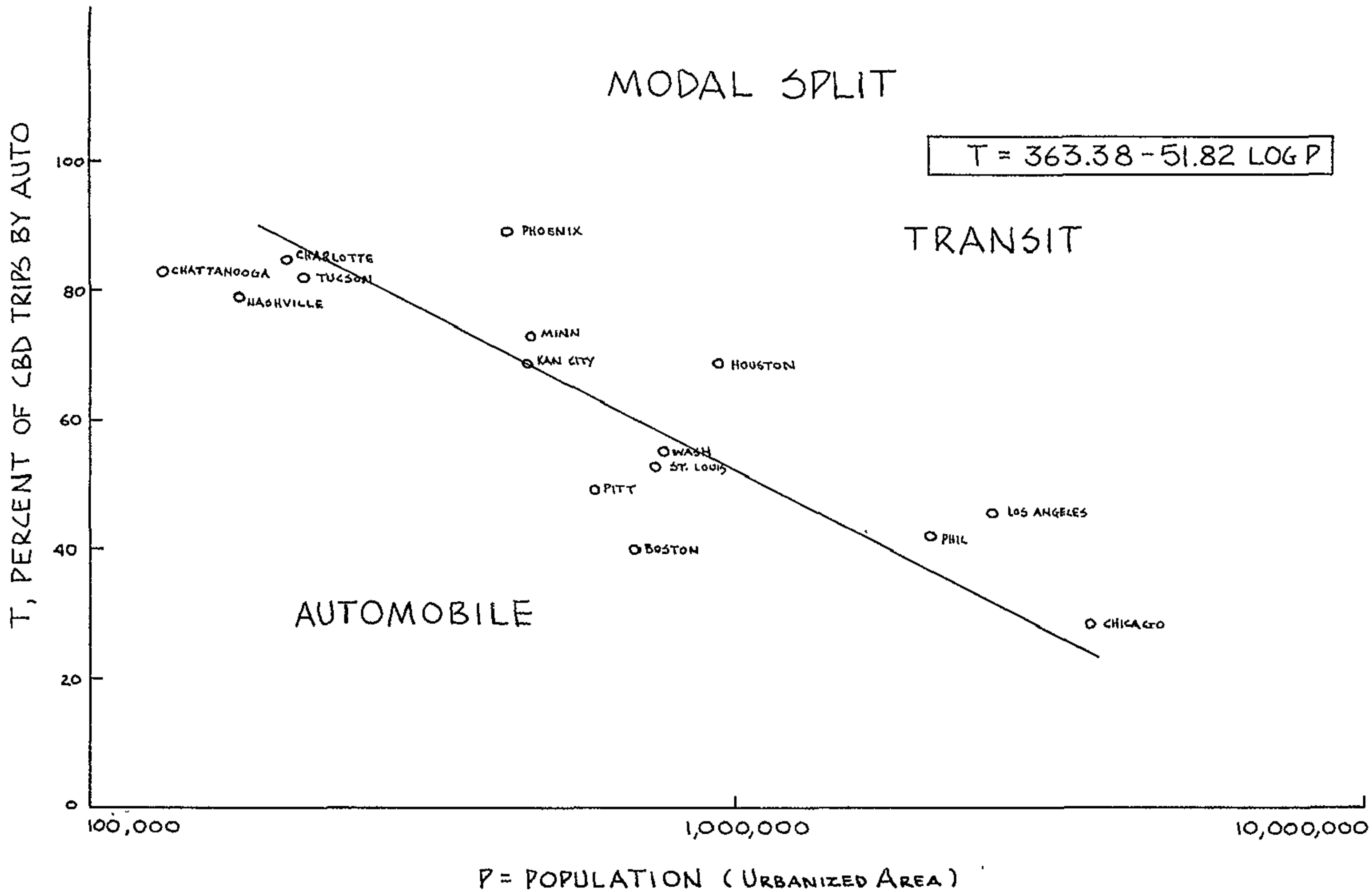

MODAL SPLIT
T = 363.38 - 51.82 LOG P
TRANSIT
AUTOMOBILE
T, PERCENT OF CBD TRIPS BY AUTO
P = POPULATION (URBANIZED AREA)
100
80
60
40
20
0
100,000
1,000,000
10,000,000
PHOENIX
CHARLOTTE
CHATTANOOGA
TUCSON
NASHVILLE
MINN
KAN CITY
HOUSTON
WASH
ST. LOUIS
PITT
BOSTON
LOS ANGELES
PHIL
CHICAGO

Figure 4.20

Automobile -

A number of additional factors must be considered when dealing with automobile travel cost. The equation is:

$$\text{Auto Cost} = \frac{1}{AO}\left(\frac{P}{2} + C_m d_1\right) + K\left(t_1 + 60\,\frac{d_1}{V_1}\right)$$

where:

AO = average occupancy

P = parking cost per day = \$1.00

C_m = out of pocket driving cost per vehicle mile = \$0.04

K = time cost per minute = \$0.02

t_1 = walking and waiting time = 6 min.

d_1 = trip length in miles

V_1 = speed in mph = 15 mph

When these equations are plotted, Figure 4.21, we see that when only one person occupies the automobile, total trip cost exceeds that of transit. As auto occupancy increases, trip cost drops below that of the transit trip.

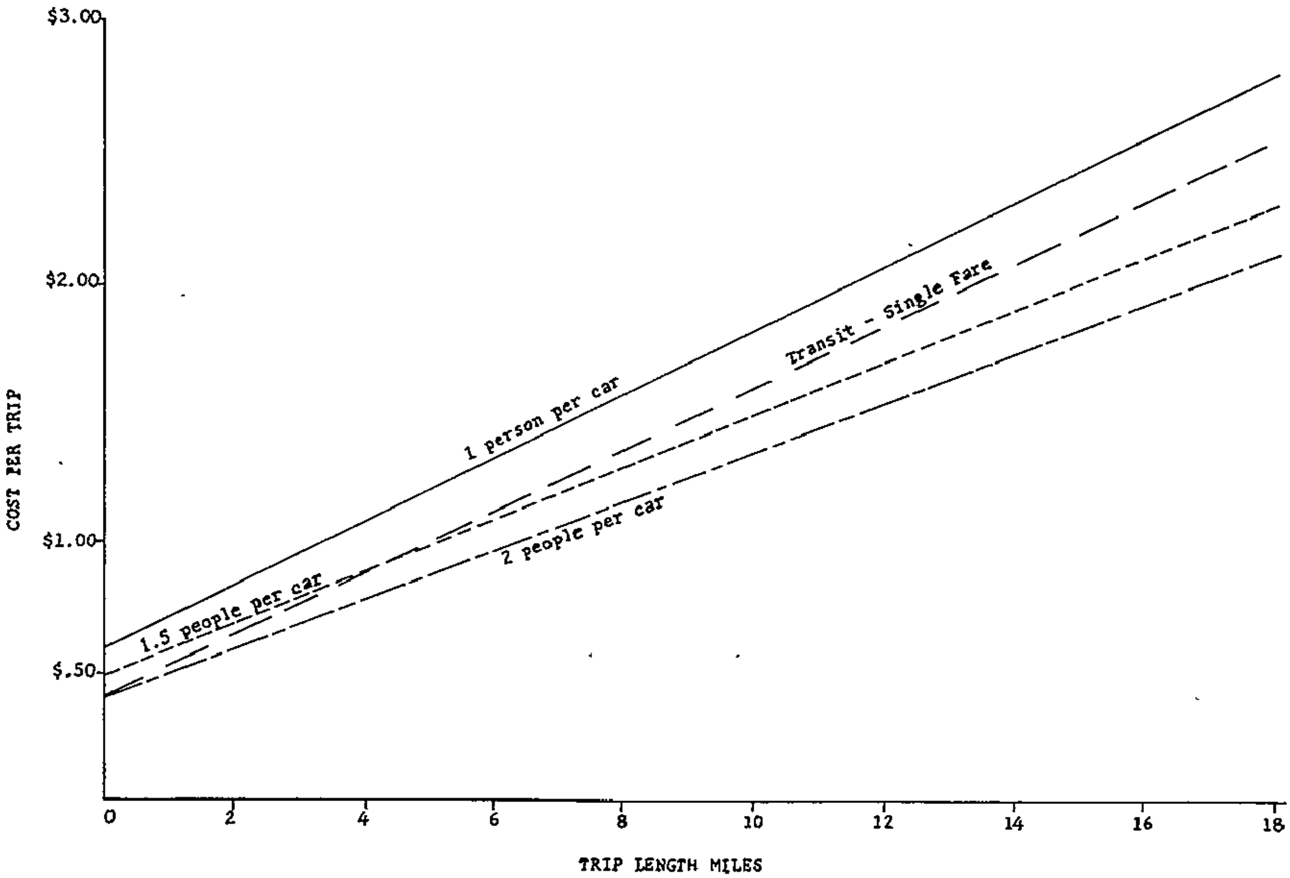
From the standpoint of the consumer, however, the transit-auto cost competition is more complex. Many of the costs associated with fees, and depreciation, are not considered in automobile operation. Another consideration is the versatility of the automobile.

4.6.3 Urban Transportation to the Airport

4.6.3.1 Airport Problem

One problem confronting modern airports is that they are dependent on a transportation mode that rarely gets more than a foot off the ground: the automobile. While aircraft have improved tremendously in speed, capacity, and efficiency, the automobile has not. Although its potential speed has increased, the automobile, through proligeration, has kept is own actual speed down. Most cars still carry only six passengers but there is little

comfort available when they do. Because the auto rarely transports its designed capacity at its designed speed, it is much less efficient a mass transporter compared to a bus, for instance. Thus, so long as 75% of the air travelers connect to their destinations via automobiles, the airports will be hampered by increasing ground congestion.



Trip Cost, by Length of Trip and Travel Mode[6]

Figure 4.21

4.6.3.2 <u>The Effects of Transportation Congestion on the Airport</u>

Although the primary emphasis of this report is intercity air transportation, it was soon realized that some discussion of ground transportation was necessary. Today's civilization is highly technical and machine oriented, as the body of this report will attest. Modern machines, men, and complex systems have become highly interdependent.

City problems also affect airports and air carriers. They are plagued by the same traffic congestion that some say will destroy or blight city cores. At the same time urbanization has become suburbanization and once remote airports now are surrounded by industry and housing tracts. There are several ways that these affect airports.

Travelers in large cities are often confronted with trips to and from airports which take as long as the plane ride. As important, the time to make the entire journey, door-to-door, is now at a par with the travel time of more traditional ground modes for short trips.

Many flights arrive and depart these busy airports at generally the same time as the morning and evening traffic rush hour. So long as this persists there can be little help for the auto oriented passenger who must fly at these times.

Most passengers are automobile oriented. Compared to mass transit modes the auto is rather inefficient. These autos require large airport access roads and a good deal of expensive land in which to be parked.

Because the bulk of passengers arrive singly, they must be similarly dealt with for ticketing and baggage. This has slowed process time within the air terminal.

The growth of facilities and services at airports has necessitated local expansion. When an airport cannot expand in place it must relocate to survive. Unfortunately the result often is that the airport is even more distant, and

inaccessible, to the potential passenger. Inaccessibility can persuade people to use other means of transportation.

Engineers have sometimes become too enrapt in their own creations. Technical advance in one area does not automatically mean advance in another. So called "Jumbo Jets" may prove more mischief than good if serious effort is not given to easing congestion problems both at the airport and on the highway.

Improvements in ground transportation will not occur without public support. The engineer must not only analyze the transportation needs of the community but also its social needs. His design must reflect both. A sound means of financing must be put forth, and the public must be made aware of the need for transportation improvements.

This list is not all inclusive, but rather given as an insight into the problem at hand.

4.6.3.3 Facing the Problem of Congestion

Two general methods are employed to ease air and ground congestion at airports: Centralization and Satellite.

Centralization methods envision to consolidation of the airline collection point and simultaneously improving the collection capability. This type includes:

1. Exclusive airport right - of - way.
2. Shuttle rapid transit to the airport.
3. Off airport auto parking combined with closed loop shuttle.

The satellite schemes envision separate airports for each category of air travel and cargo. This method includes:

1. Construct new, exclusive type airports while maintaining present airports.

2. Limited purpose airports with separate terminals, runways, taxiways and ground transit connections but located in the same general area.

3. The use of off-airport or downtown terminals with scheduled transit to the airport.

4.5.3.4 Rapid Transit and the Automobile

The automobile will apparently remain the primary ground link to the airport. Aside from relocating airports, three steps must be taken to ease ground and terminal congestion associated with airports: more efficiently provide for the automobile, provide community rapid transit, and improve baggage handling and ticketing (See Section 4.5).

One promising method to improve automobile use is to relocate parking at some distance from the airport. For example a valet-type, multistory parking garage within a mile or so of the air terminal is one method. While this would not significantly cut travel time or road congestion it would ease parking and terminal congestion. Within the parking garage would be located complete ticket validation and baggage handling facilities. The passenger and his baggage could be moved to the terminal proper via small monorail, as proposed by Braniff at Love Field in Dallas, or other shuttle. The passengers could then proceed directly to the gate while his baggage is moved to the aircraft. Alternatively the passenger could leave the shuttle away from the main terminal and in fact never go near this area. A connection between the shuttle and a "horizontal" elevator similar to those at Tampa International could further improve passenger flow.

Off airport parking at relatively short distances would not improve the congestion of the roadways. Greatly expanded or elevated expressways or limited accessways would be needed to complete this system.

Additional to off-airport parking is rapid transit, primarily rail and bus. Today our only operating rapid rail transit to an airport is at Cleveland, Ohio. It has proven to be rather popular and carries about 4000 passengers per day. Rail transit is particularly suited to very high speed, high volume demand and is a proven system.

Buses have been used for some time at airports throughout the country and carry some 22% of all airport ground traffic. Unfortunately at present buses must compete equally with autos, trucks, etc., on the freeway. Recent proposals for "Busways," roads restricted to buses only, would seem a great improvement over the present situation. Buses are also suited to large demand transit but "busways" are as yet unproven.

Another use of the bus involves modern small buses which are small enough to negotiate neighborhood streets. Radio dispatched and operated for the airport rather than individual air carrier these buses could pick up and deliver passengers at the door step similar to a taxi. A similar computer system has been operated in Flint, Michigan.

Other rapid transit concepts were considered but were rejected for this report. Many of these systems have never been tried and too little data is available about them. They are:

1. Monorail
2. Urbmobile
3. Glideway
4. Guideway
5. Dart
6. Carveyor
7. StaRRcar

Thus rapid transit concepts and costing were limited to the bus and rail car only. This is not meant to imply that any other system should not be considered. On the contrary, all proposals should be considered and the one best or combination of best suited to a situation used.

4.6.3.5 Results and Conclusions

The results of this investigation are:

1. Traffic improvements are necessary to keep pace with airport and air traffic expansion.
2. To about 12,000 passengers per hour the bus with busway is theoretically the most economical rapid transit.
3. Above 12,000 passengers per hour the rail car is an efficient rapid transit.

The traffic and congestion situation is such that any Rapid Transit should be considered, but more important, some Rapid Transit must be used to insure the growth of the community and the airport serving it.

4.6.3.6 Recommendation

The time of hesitancy by city governments and transportation authorities is over. In order to adequately meet the demands of the future, a sound rapid transit or improved highway and parking system must be proposed, debated, and evaluated. Easing airport congestion helps not only the airlines and airport, but more important—it insures continued growth for the host community. The engineer must recognize the varied needs of the city and design accordingly. The populous must be kept informed of the need and benefits of improved traffic conditions. At the same time, the airlines should give strong consideration to the relocation of terminal services.

All of these activities must be coordinated so that the final result will be the most advantageous system possible.

4.7 Conclusions

In testing the model to determine location of STOL ports relative to CTOL ports, we discovered that the STOL port is always located on the opposite side of the city relative to the CTOL port or S/CTOL port.

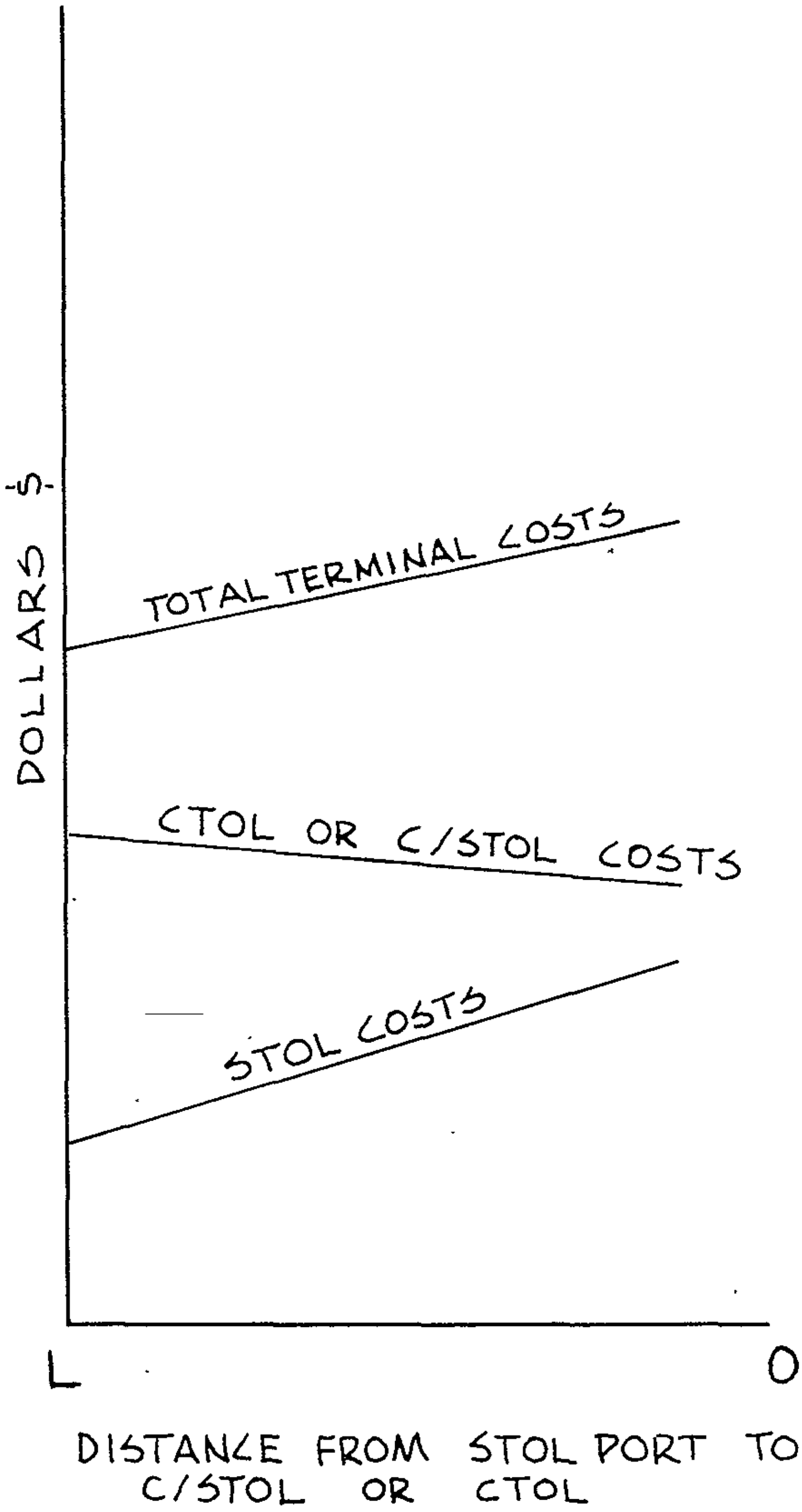
The reasons seem to be exemplified by Figure 4.22. In that figure, one will note that for a square city of side L, the total terminal cost of STOL related facilities plus CTOL facilities is at a minimum when the distance between them is L.

This suggests that land costs rapidly outweigh ground access costs. This can be seen in Figure 4.23 where as access costs reach a minimum land values skyrocket.

Based on this, we would have to say that unless the traveler's value of time increases sizeably or unless unusually low cost land is available near the city center, airports should continue to be located near the periphery of the urban area.

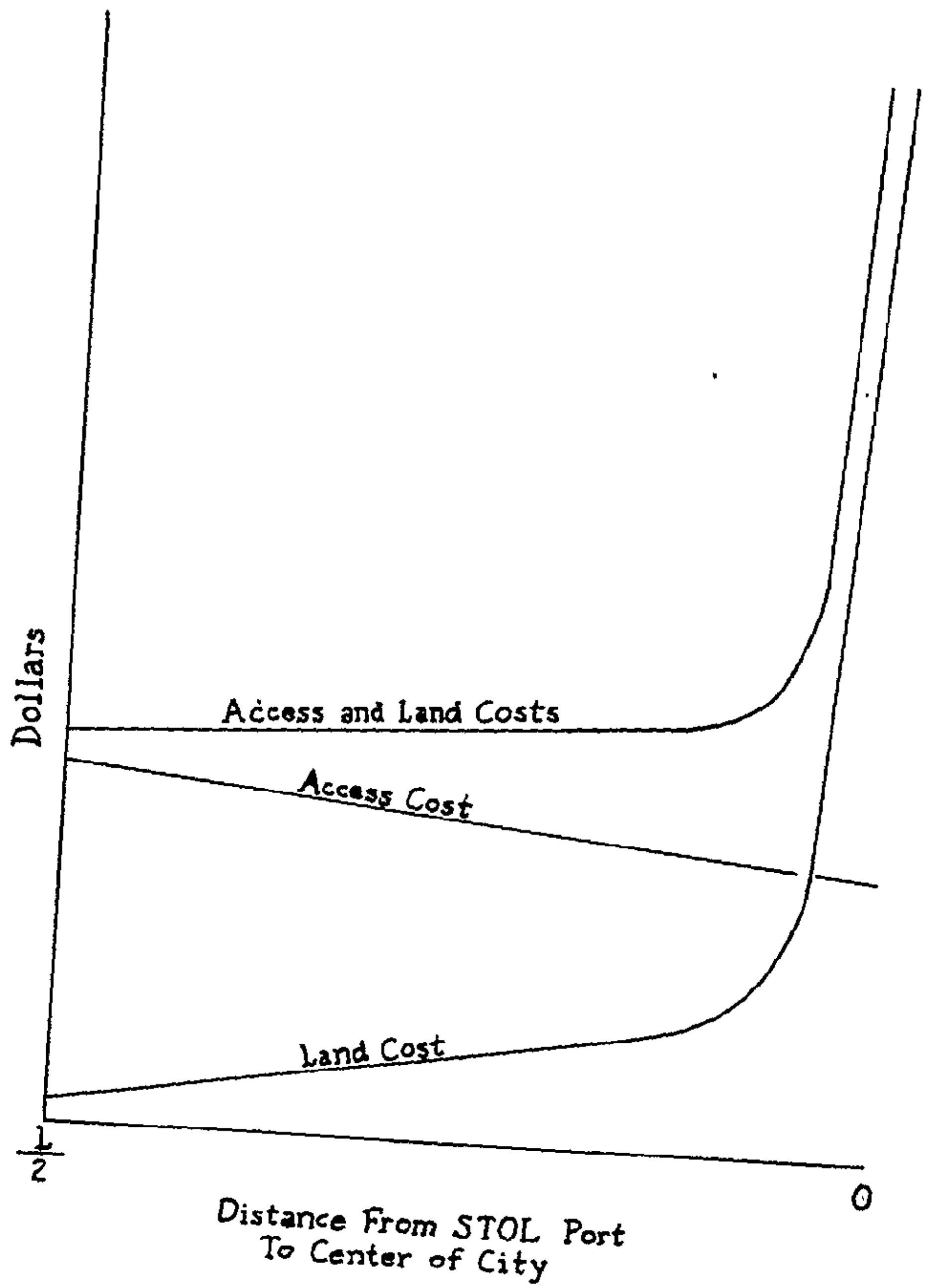
It should be apparent that the application of the system's approach to terminal location and design lends itself to allow the planners to relate the air terminal to the whole urban area. All too often, public projects as massive as an airport tend to see their problems and the problems they create purely from the standpoint of what is in their own interest. Technology must move beyond this to a more sophisticated and human viewpoint.

Man not only shapes his environment, but is shaped by it. The systems approach allows the engineer and persons in other disciplines such as economics, sociology, architecture, political science, and urban planning to evaluate the tradeoffs and implications of their professional decision making.



LOCATION OF STOL PORTS RELATIVE TO CTOL PORTS

Figure 4.22



LOCATION OF STOL PORT RELATIVE TO CITY CENTER

Figure 4.23

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CHAPTER 5

AIR VEHICLE DESIGN

5.1 Introduction

The objectives of the air vehicle design group were to provide a variety of aircraft design configurations and a means of obtaining cost data for each design.

This was accomplished through the development of mathematical models for aircraft design, computation of initial aircraft cost and direct operating cost.

In order to narrow the scope of the problem in face of limited time and personnel available for the study, certain assumptions and restrictions were applied. A major decision of this type was to restrict the design group's efforts to consideration of configurations of the fixed wing turboprop STOL (short take-off and landing) aircraft. There will be no attempt to justify selection of the fixed wing turboprop over other STOL, VTOL (vertical take-off and landing) and CTOL (conventional take-off and landing) aircraft. It is felt that the systems approach utilized in this study is applicable to other aircraft systems, and it is desirable that similar studies be conducted on other types of aircraft designs to provide a complete evaluation of all available systems. It should be pointed out that the decision to consider only the fixed wing STOL aircraft affected the decisions of the other groups participating in the study by narrowing the range of options available to these groups in their analyses. In the following sections, the procedures employed by the air vehicle design group are described.

5.2 The Air Vehicle Design Model

5.2.1 Design Model Parameters

The choice of input parameters to the design model was the following: the number of passengers, the design range, and the cruise speed. Originally, cruise altitude was included as a separate input, however, it was later assumed to be a linear function of cruise speed. Some of the more significant output which were generated from the model included the following parameters: gross weight, a component weight breakdown, physical aircraft dimensions and wing area, engine thrust, and runway length required for take-off. With the exception of runway length required, all of the generated output was used in a direct manner by the cost analysis model.

5.2.2 Design Model Procedure

The approach used to provide the desired output involved an iteration procedure to determine the correct total gross weight and wing area of the aircraft which results in optimum cruising conditions. The number of passengers required determines the fuselage size and the cruise speed provides a design altitude so that cruise air conditions are known. At this point the iteration begins by assuming an arbitrarily small value for wing area (50 square feet). Now enough information is known to determine Reynolds numbers for the wing and the fuselage, making possible calculation of cruise parasite drag coefficient, C_{D_o}, and the lift coefficient, C_L, which results in the optimum cruise conditions. For optimum cruise, the lift to drag ratio, L/D, is a maximum, thus yielding optimum use of the wing at a given speed. For this case:

$$C_L = (C_{D_o} \cdot \pi \cdot e \cdot AR)^{1/2}$$

where

C_{D_o} ---- parasite drag coefficient

e ---- wing efficiency assumed 0.87

A_R ---- aspect ratio assumed 7.0

and

$$L/D_{max} = C_L/2 \cdot C_{D_o}$$

If the calculated value of C_L becomes greater than 0.5 then there is a possibility of wing stall due to vertical gusts. Therefore, if C_L is calculated to be greater than 0.5 then it is set at 0.5 and the corresponding L/D is determined by:

$$L/D = C_L/(C_{D_o} + C_{D_i})$$

where:

$$C_{D_i} = C_L^2 / (\pi \cdot e \cdot AR) \text{ is the induced drag coefficient.}$$

Knowing C_L allows a first approximation of the total gross weight, WG1, from the basic equation:

$$WG1 = 1/2\ C_L\ \rho\ V^2 S$$

where:

C_L ---- lift coefficient

ρ ---- air density at cruise altitude

V ---- cruise velocity

S ---- wing area

At this point the various component weights were calculated based on the input parameters, wing area, and the first approximate gross weight, WG1. The summation of these weights yields the second approximation of the gross weight, WG2. At this point, had WG1 and WG2 been identical, we could logically conclude that the assumed wing area at the beginning of the iteration was the correct wing area. In general, however, this was not the case. Therefore, we form the quantity, ΔWG, where

$$\Delta WG = WG1 - WG2$$

and store this value.

The procedure now is to go back to the beginning of the iterative loop and incrementally increase the assumed value of the wing area and repeat the process until a new value of ΔWG is determined. This is continued until wing area has reached some logical maximum value (3000 square feet, for example), and for each assumed wing area, there is a corresponding value of ΔWG. At this point a search is made all of the values of ΔWG, and the final design selected is the wing area, gross weight, and all other related parameters which correspond to the smallest value of ΔWG. (Figure 5.1).

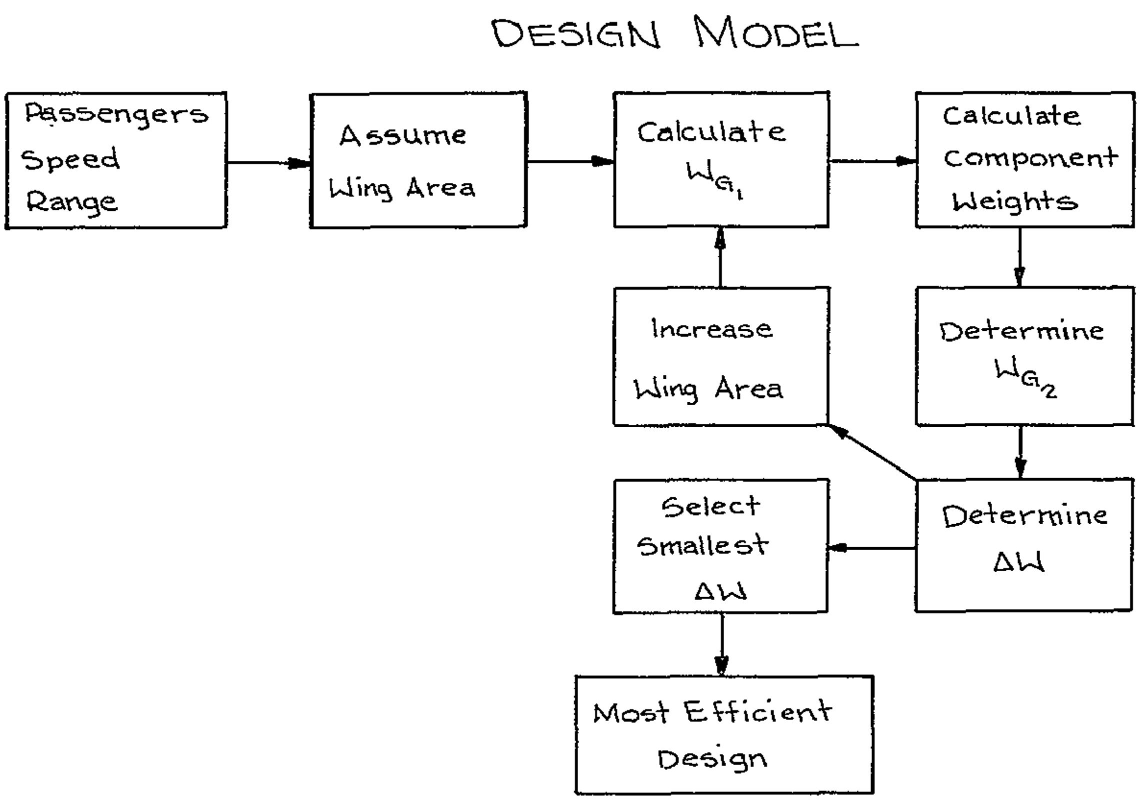

Figure 5.1

At this point, all of the required output has been determined with the exception of runway length. To find this parameter, it is necessary to assume a value for lift-off velocity which was taken to be 118.5 fps, and we must further assume that take-off or roll acceleration is constant.

Under these assumptions, it can be shown that the distance to lift-off can be found from:

$$D_{lift\text{-}off} = 1/2\ V^2_{lift\text{-}off} \ / \ a_{roll}$$

Now runway length is approximately:

$$RWL = 1.5\ (D_{lift\text{-}off})$$

The acceleration available is calculated from Newton's Law:

$$a_{roll} = \frac{Force \cdot g}{WG}$$

It was assumed that roll acceleration should be limited to 10 fps^2 to avoid passenger discomfort. Therefore, if roll acceleration was found to exceed this maximum value it was set to 10 fps^2 for purposes of calculating runway length and thus only a fraction of the available thrust would be utilized during take-off.

In calculating roll acceleration, the force acting on the aircraft is found by

$$Force = (Thrust_{roll} - Drag_{roll}) - WG \cdot \mu$$

where μ is the ground roll friction taken to be 0.2. Roll thrust can be found from a knowledge of cruise thrust, which was calculated previously, and roll drag is calculated based on sea level drag coefficients and lift off velocity.

Appendix 5-A contains specific data and formulas employed in the aircraft design model, including a reproduction of the computer program used.

5.3 Interior Configuration

5.3.1 Aircraft Interior

Consideration of interior passenger seating and accommodations is necessary in the design of any passenger aircraft. An analysis was made of several possible seating arrangements for each passenger load con-

sidered in the study, and fuselage length and width were determined from these studies for use in the design model.

Some assumptions were made in regard to passenger seating. It was determined that all seating would be of a single class, with a seat width of 20 inches and a seat pitch of 34 inches. This is comparable to the tourist class seating planned for the new generation of "jumbo jets" and to first class accommodations in some present commercial aircraft.

5.3.2 Fuselage Length

Determination of fuselage length was obtained through use of the equation presented in MIT Flight Transportation Laboratory Technical Report F-T-66-1, "Analysis of V/STOL Aircraft Configurations for Short Haul Air Transportation Systems":

$$\text{Fuselage Length (ft.)} = \frac{\text{No. of Passengers}}{\text{Seats Abreast}} + 3.7 \cdot \text{No. of Doors} + 4.5 \cdot \text{No. of Toilets} + 27.5$$

Cockpit and tail assemblies are accounted for with the inclusion of a constant value of 27.5 feet, while the other terms are self-explanatory.

Seating arrangements of four, five, six, and seven passengers abreast were considered for loads of 40, 60, 80, 100, 120, 140, and 160 passengers (Figure 5.2).

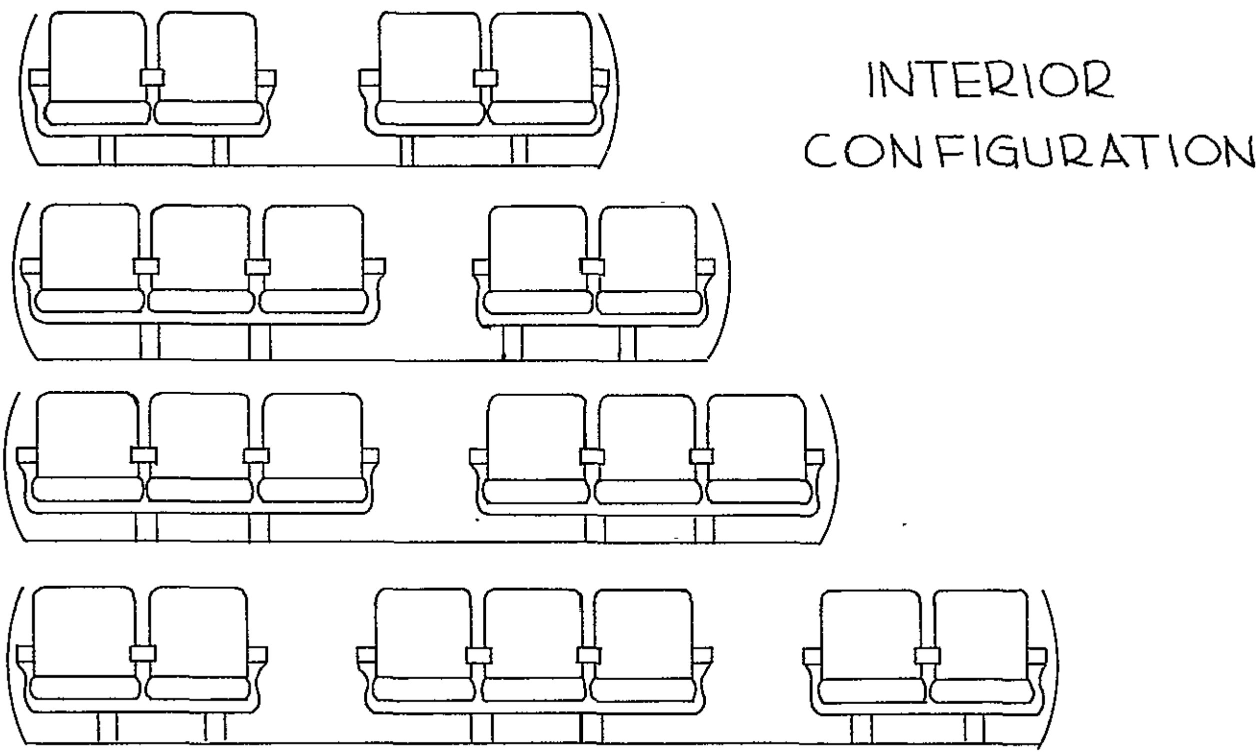

Figure 5.2

Number of doors and number of toilets were assumed for given passenger loads as shown in Table 5.1.

Passenger Accommodations

No. of Passengers	No. of Doors	No. of Toilets
160	3	4
140	3	4
120	3	3
100	2	3
80	2	2
60	2	2
40	1	1

TABLE 5.1

Toilets are assumed to be located opposite one another when possible, thus no increase in fuselage length was calculated when the number of toilets was increased from one to two or from three to four.

No additional fuselage length was provided for the accommodation of buffets for food preparation or for cloakroom space. It is assumed that these facilities can be provided when desired at the cost of some passenger capacity.

Computed values of fuselage length for each passenger load and seating arrangement considered are shown in Appendix 5-B.

5.3.3 Fuselage Width

Fuselage width was obtained by modification of an equation presented in the reference cited above. The following was used: Fuselage width = seat width · seats abreast + aisle width + dead space. As previously mentioned, seat width of 20 inches was used, along with an aisle width of 18 inches. Dead space of 8 inches in fuselage width was assumed.

Computed values of fuselage width are shown in Table 5.2

Fuselage Width

No. of Seats Abreast:	4	5	6	7
Fuselage Width (ft):	8.8	10.5	12.2	15.3

TABLE 5.2

It should be noted that a second 18-inch aisle was added in the seven passenger abreast configuration.

5.3.4 Seating Arrangements

The above computations provided fuselage length and fuselage width for each combination of passenger load and seating arrangement.

Fineness ratio, or ratio of aircraft length to width was next computed, and those seating arrangements most closely approximating the median value of fineness ratio were the arrangements selected for each passenger load.

As a result, the following seating arrangements were selected for passenger loads shown:

Selected Seating Arrangements

No. of Passengers	No. of Seats Abreast
160	7
140	7
120	7
100	6
80	6
60	5
40	4

TABLE 5.3

5.4 Aircraft Cost Model

The function of the aircraft cost model is to develop aircraft cost figures for the overall system cost-effectiveness model. The output of the model is a cost figure for the design, procurement and operation of a fleet of aircraft through 1985. A computer program is used to calculate the design, procurement and operation costs from basic aircraft design parameters such as gross weight, speed and thrust. The model is divided in two parts:

- Initial cost
- Direct operating cost

5.4.1 Initial Cost

The basic approach employed involves the use of regressional equations derived from aircraft already constructed. The primary source of these equations are reports RM-4845-PR & RM-4670-PR published by the Rand Corporation. These equations are applicable to all conventional fixed wings aircraft. They are used in the cost calculation of short take off and landing aircraft (STOL) with some corrections in order to consider the complexities in design and manufacturing of this type of aircraft. The initial cost is considered in two parts:

- Development cost
- Production cost

5.4.2 Development cost

This is the non-recurring expense of the design stage of the aircraft. It is assumed that the design stage covers 3 years. The development cost is equally spread over this period of time and carried through to 1985 with a 6% rate of interest. In the development cost we consider:

Initial Engineering: The engineering cost required to produce one airframe. Speed and thrust of the engines are used as parametric variables.

Development Support: The manufacturing effort in support of the engineering during the development stage. This includes labor and material for test parts, mock-ups and other hardware. This expense is considered a percent of the initial engineering cost.

Flight test operations: The cost of the test of performance and control characteristics of the aircraft and the operation of its major subsystems. The variables that affect this cost are gross weight, speed and the number of test aircraft built.

Initial tooling: The expenditures in tooling realized before the first airframe is produced. The variables that affect this cost are gross weight, speed and the production rate of aircraft.

Production Cost of Test Aircraft: The cost of building the test aircraft in accordance with the production cost estimating method, including engines.

Engine Development Cost: The expense incurred in preliminary design, engineering and tooling of the prototype, the materials and bench testing and the cost of improvement of the engine performance. This is accomplished during the production stage. This cost is affected by the required thrust of the engine and the number of engines to be built. In this model engine development cost was not considered since off-the-shelf engines will provide required performance characteristics.

Production Cost: The recurring costs that occur during the manufacturing stage of the aircraft. In our project we consider three years for manufacture of the aircraft fleet. The cost is equally spread over this period of time, and carried through to 1985 with a 6% rate of interest.

5.4.3 Production Cost

Sustaining Engineering: The cost of engineering required to maintain the production. This covers any changes in the design and update of the original design. It is affected by the number of aircraft to be built and the initial engineering expense.

Sustaining Tooling: The cost of maintaining and replacing tools and other related services in the production stage. This cost is affected by the number of aircraft being built and the initial tooling cost.

Manufacturing Labor: The cost of labor required to build the aircraft. The effect of the number of aircraft being built is an important factor. A

75 percent cumulative average learning curve accounts for the reduction of unit cost as the production progresses from unit one to unit N. The variables that affect manufacturing labor are gross weight, speed and number of aircraft.

Materials Cost: This cost is also affected by the production run. In this case an 89 percent cumulative average learning curve is used. The materials costs are affected by gross weight, speed and the number of aircraft to be produced.

Engine Production Cost: The cost of fabricating and assembling engines, including labor, material, overhead, profit and sustaining tooling. It is affected by the engine thrust and the number of engines to be built.

Furnishing and Equipment: The cost of seats, air-conditioning, lavatories and other passenger conveniences. A direct empirical relation between the number of passengers and the furnishings cost is utilized.

5.4.4 Direct Operating Cost

This portion of the cost model considers the cost of operation of a fleet of aircraft over fixed routes. The method utilized to compute the direct operation cost of the aircraft is that of the Air Transport Association of America (ATA). This method of calculation leads to results slightly different than those published by commercial airlines but it is widely used by the aircraft manufactureres and commercial airlines as a means of comparison of the operating economics of competitive aircraft. As in the initial cost model some correction factors are employed to provide for the increase in maintenance cost of STOL aircraft due to the more complex design, compared with conventional aircraft. The Direct operating cost model is divided in two major parts:

- Flight Operations
- Direct Maintenance

5.4.5 Flight operations: The expenses incurred during the flight of the aircraft, to include:

Flight crew cost: Crew salaries, training and travel expenses. This cost is principally affected by the gross weight of the aircraft.

Fuel and Oil: The cost of the fuel and oil burned by the aircraft. This is an important item in the direct operating cost. It is assumed that the fuel utilized is JP-4 with a cost of 0.105 \$/gal. and the oil is synthetic jet oil with a cost of 7.50 \$/gal. This cost depends on the fuel consumption rate of the aircraft and the distance traveled by the aircraft.

Hull Insurance: It is assumed that over the useful life of the airplane, the hull insurance has an average value of 2% per year, and also that insurance will cover the initial price of the complete aircraft.

5.3.2. Direct Maintenance: The labor and material cost for inspection, servicing and overhaul of the airplane and accessories. This is a function of the gross weight, thrust, price of the aircraft and distance traveled. It includes:

- Airframe Labor
- Airframe Materials
- Engine Labor
- Engine Materials
- Maintenance Burden

5.4.6 Special Considerations

The equations for the initial cost calculation were derived for military fixed wing type of aircraft. They are being used for the commercial STOL concept, which may be questionable. Possible error in comparison of competing systems is minimized, however, since cost comparisons are achieved by subjecting both the STOL designs and conventional aircraft to which comparison is made to the same cost model.

The ATA method of direct operating costs may produce some error in STOL application, since maintenance of unique features such as extended flaps and a propeller interconnecting system may increase operating costs. An additional factor not considered is that short haul aircraft are subjected to more landings and take-offs than present longer haul aircraft, resulting in a possible increase in costs. Changes in costs of major aircraft components could have a significant effect on system cost.

5.4.7 Remarks

1. Labor costs are considered in terms of 1969 dollars per man hour.
2. The total cost has been transformed to a 1985 value with a 6% compound interest rate.
3. Avionic costs are included in the Air Traffic Control system cost.
4. The test aircraft are considered to be used after the testing stage as production units, therefore, the production cost is calculated for (N-TA) aircraft instead of N(TA = Number of Test aircraft).
5. In cost comparison with existing aircraft, development cost was not considered. Production cost of the L-1011 was based on cost of the 200th unit.
6. Aircraft over 120000 lb. of gross weight are considered to have a three man crew aircraft for operating cost purposes.
7. The utilization (block hours per year) factor of the aircraft is considered a function of the block time. Short haul aircraft are subjected to a smaller utilization then long haul.
8. An increase of 5% has been assumed for STOL aircraft in initial engineering, tooling and manufacturing labor costs to account for complexities in design as compared with conventional aircraft. An increase of 204% has been assumed in the production cost of engines to account for the cost of propellers and their interconnection system in STOL design.

9. An increase of 10% in direct maintenance cost has been applied to STOL aircraft in order to account for complexities in maintenance.

10. In the equations for the initial cost calculation, the dollar cost per hour of labor, engineering and tooling includes the following:

    - Direct Labor
    - Overhead
    - General and administrative charges
    - Quality control
    - 10% profit of the airframe manufacturer

5.4.8 Cost Model Computer Program

The computer program calculates the development, procurement and operating costs in a direct form, leading to a single cost figure for a fleet of aircraft to operate in the route model. The input information utilized is supplied from the Design Model, the Control Model and the Route Model.

Input from the Parametric Design Model

- Maximum gross weight
- Weight empty less engine weight
- Weight of propeller interconnecting system
- Number of engines
- Engine thrust
- Lift over drag coefficient (L/D)
- Cruise speed
- Design range
- Time to climb to and descend from cruise altitude
- Number of passengers

Input from Control Model

- Production run of the aircraft
- Average flight distance

Input from Route Model

- Production run of the aircraft
- Average flight distance

5.5 Current Aircraft Concepts

The following aircraft have been selected as being representative of the current aircraft system and are considered typical of the conventional aircraft (CTOL) operating in the 1975-1985 time period:

Lockheed L-1011
Boeing 747
Boeing 727-200
McDonnell-Douglas DC-9 Series 30

Upon consideration of the characteristics of these aircraft, the Lockheed L-1011 was selected to represent CTOL aircraft in the route model. Appendix 5-D depicts the CTOL aircraft information gathered. A flow chart of the cost model is included in Appendix 5-C.

CHAPTER 5 REFERENCES

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CHAPTER 6

AIR TRAFFIC CONTROL

6.1 Scope of the Problem

6.1.1 A Problem of Delay

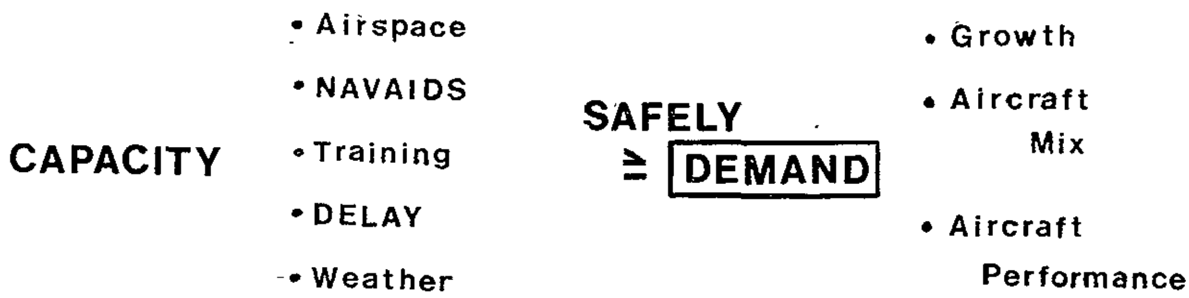
The awesome problem of today's air traffic control is simple yet overwhelming. Stated in its most elementary form, aircraft are flying faster and faster to longer and longer waiting lines. It was possible to fly from Frankfurt, Germany to New York in about 14 hours, including landing, in 1960. During July, 1968, some flights on the same route completed the trip in 5 hours but took another 3-4 hours to land. In terms of facts and figures, 292 airports in the United States accumulated a total of 330,000 hours of delay (aircraft hours and NOT man hours) in 1966. Thus, recent increased volume high speed aircraft have flooded the present air traffic control system and predictions are of a worsening of the present situation.

Thus the design of an air traffic control system, in conjunction with a common carrier aircraft system (USA, '75-'85), is quite necessary. It is intended to approach this design task by first formulating the general air traffic control problem and then, by comparative analysis, determine the system that most efficiently and economically provides adequate control.

Formulation of the Air Traffic Control (ATC) problem first requires digression to a clear description of the purpose of air traffic control. Air traffic control exists primarily to provide safe and efficient flight instructions for large numbers of aircraft travelling. . . (instrument flight rule (IFR) and visual flight rule (VFR) at varying altitudes) to and from random points at scheduled and unscheduled times. Basically,

then, pilots wanting to fly between two or more points create demand. This demand is a function of traffic growth, aircraft mix (by type), and aircraft performance. The demand must be satisfied by the capacity to fill it. This capacity is a function of airspace, navigation aids, training, delay and weather. Further, there is a capacity ceiling, or delay criteria (presently 4 minutes delay established by the Federal Aviation Administration (FAA) which is defined as average maximum acceptable delay beyond which a particular air traffic control situation may not go due to threatened saturation.

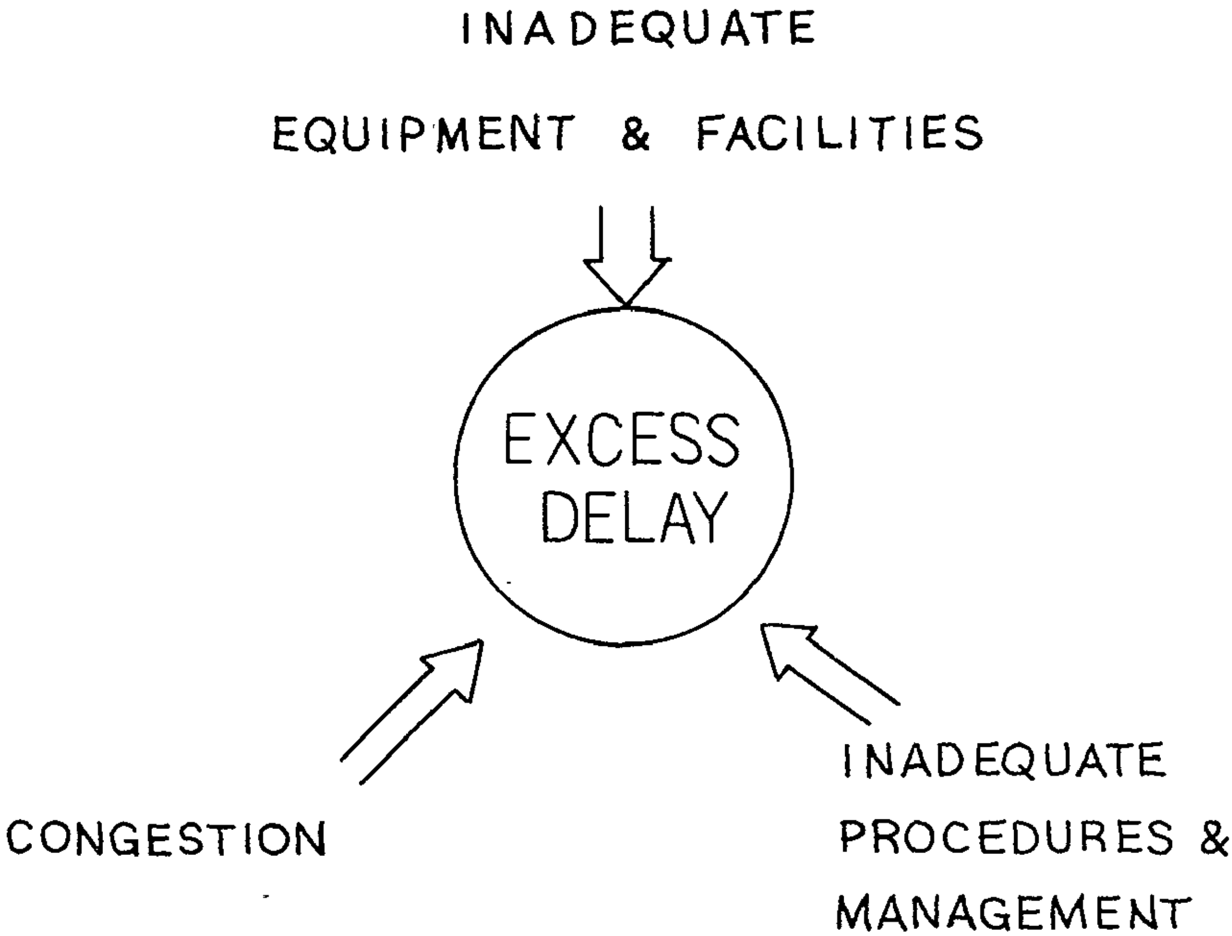
Thus, in simple equation form, air traffic control is an attempt to provide capacity sufficient to satisfy demand in a safe manner (Figure 6.1).



Capacity Versus Demand

Figure 6.1

This analysis leads to the determination that excess delay and not unsafe conditions is the primary failing of the air traffic control system. This same delay is a result of three causes (Figure 6.2). Congestion, the first, is simply too much demand. The second, inadequate equipment and facilities means primarily that the equipment and facilities are not capable of doing the job asked of them. Finally, inadequate procedures and poor personnel management, which are human engineering and management problems.



Causes of Delay

Figure 6.2

Additionally, the following situations emphasize the causes of delay and illustrate the basic weaknesses of the present air traffic control system:

1. Control and controller capacity are often exceeded during peak periods.
2. Sudden "surges" of demand at specific centralized control facilities cannot be adequately handled without adverse delay in other portions of the system.
3. Weather has become increasingly more influential in its effects with increased traffic and higher velocity aircraft.
4. Landing accidents have disproportionately increased. (See paragraph 6.2.3.1, Safety.)

6.1.2 Objective

It was quite obvious that present trends of increased delay are unsatisfactory for commercial aviation. Therefore, the specific objective, in the air traffic control area, was to design a satisfactory air traffic control system that would yield acceptable delay levels. This design was to have been completed in consideration of that level of delay specified as maximum. Thus, specific design objectives were:

(1) Design of an air traffic control system capable of satisfactorily accepting the air traffic load 1975-85.

(2) Design of an air traffic control system such that delay will be less than the delay criteria.

(3) Design of an air traffic control system capable of being tailored to any specific terminal area (HUB).

6.2 Design Formulation

6.2.1 Background

The existing basic philosophy of air traffic control designates controlled and uncontrolled airspace. The airspace is geographically divided into enroute sectors and terminal areas (HUB). Practically, control of aircraft is exercised by positive control in centralized operations (such as terminal areas and lanes or air routes through enroute sectors) while control in decentralized operations is nominal. This is basically a positive ground based separation service.

The design approach taken was to model a generalized air traffic control system by digital simulation. The simulation was intended to reveal comparisons of the different possible systems available or capable of development. It was necessary to outline several simplifying assumptions:

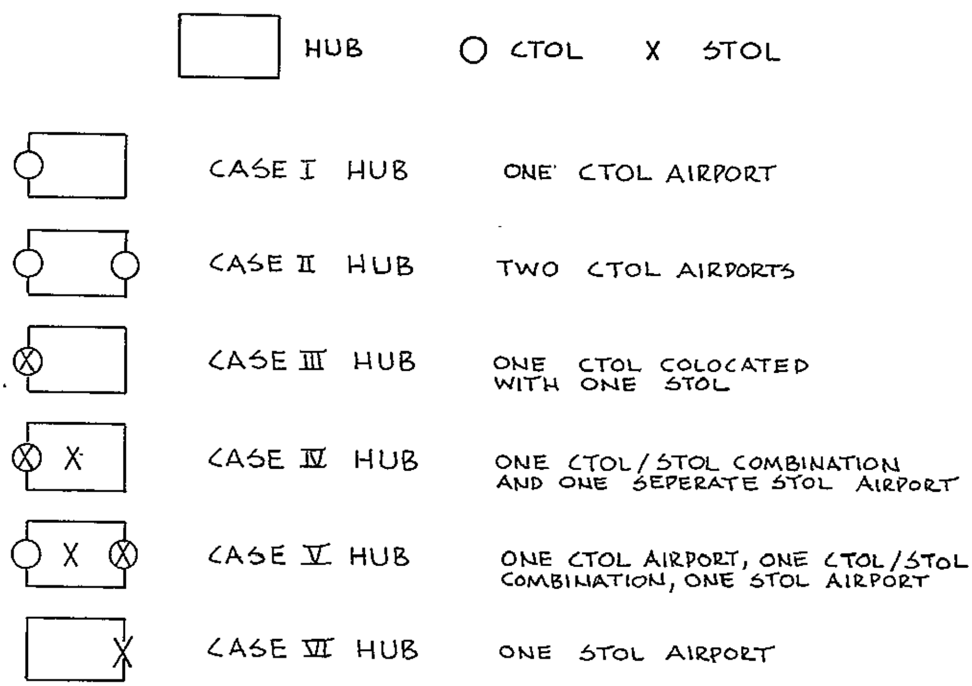
(1) It was assumed that a terminal area, or HUB as it was designated,

was definable with a specific boundary beyond which aircraft congestion was negligible.

(2) It was assumed that the present method of probability of safe flight by aircraft separation would continue although separation criteria might change.

(3) Two basic runway configurations were assumed. One was a single runway and the other, parallel runways spearated by 5000 feet.

(4) Six basic HUB airport configurations (or cases) were adapted for consideration in conjunction with design groups of the common carrier project. They were combinations of STOL (Short Take Off and Landing) and CTOL (Convential Take Off and Landing) port configurations. Additionally, it was assumed STOL aircraft would be capable of utilizing CTOL facilities but the converse was not acceptable (Figure 6.3).



Six Basic HUB Configurations

Figure 6.3

(5) It was assumed that IFR operating conditions were in effect and that each runway of a particular configuration had only one approach and departure pattern.

Reasonable constraint requirements were also considered:

(1) Realistically, any system or subsystem designed must be compatible with the system presently in existence. This requirement was necessary as a result of prohibitive costs and retraining requirements.

(2) An air traffic control system for 1975-85 must conform with NAS STAGE A (See Appendix 6-C, NAS STAGE A description).

(3) Instantaneous aircraft arrival and local flight generation are not politically controlable (Random arrival will continue).

(4) Conformity must be established within existing technical and physical limitations.

(5) Delay reduction was to be accomplished only by expansions and improvements of equipment and facilities.

(6) System design of facilities at each HUB must be considered an independent procedure because the requirements of each were different. This is not to say that the functioning of each HUB is independent of all others.

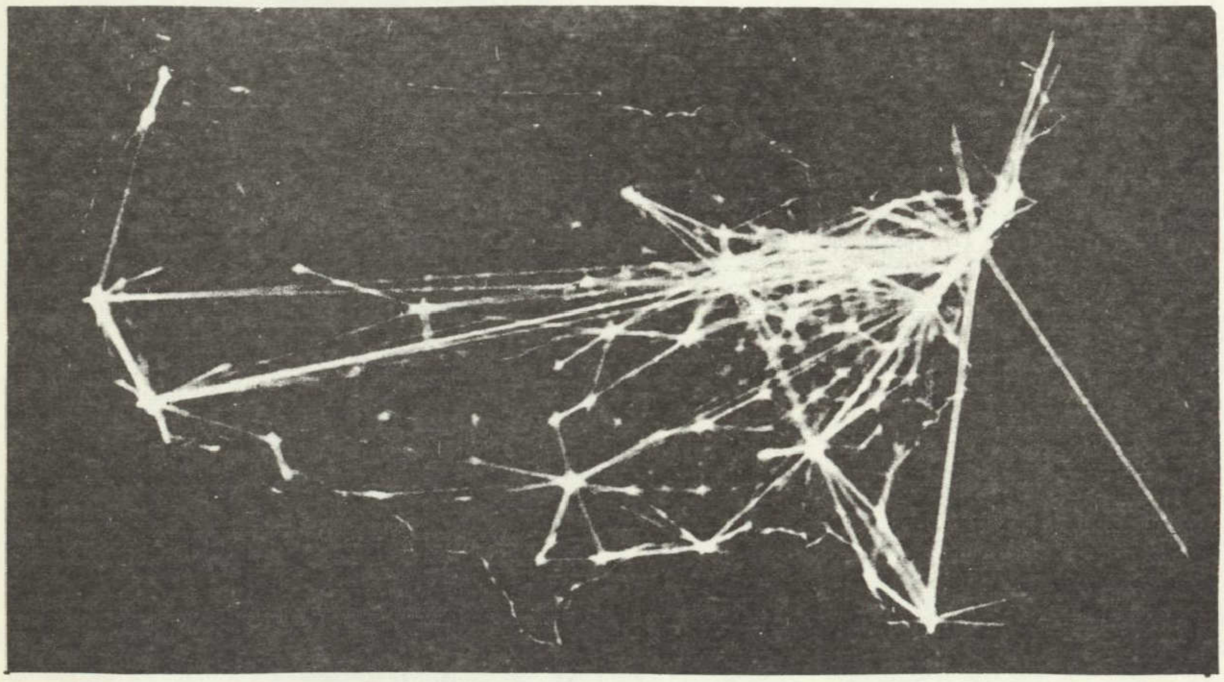
(7) Safety requirements of an air traffic control system must conform with presently indicated trends of safety levels (See Paragraph 6.2.3.1).

6.2.2 <u>General Approach</u>

It was determined that delay is caused by (1) Congestion, (2) Inadequate equipment and facilities, and (3) Inadequate procedures and personnel management (See Figure 6.2). Consideration was only given to redesign of equipment and facilities. National Airspace System (NASA) Stage A design

considerations and follow on Stages B and C will ultimately attempt to provide relief for congestion (See Appendix 6-C). Procedure and personnel management changes were not considered because "real time" simulation modeling would be required to measure the effect of such changes.

Consideration of traffic patterns (See Figure 6.4, Cartographatron of Air Traffic Patterns) makes apparent the criticality of the terminal area or HUB as it is herein defined. It was therefore mandatory to plan each HUB as an integral part of the system. Further, a method of evaluating the effectiveness of any particular HUB would be necessary in order to predict maximum capacity.



CARTOGRAPHATRON TRAFFIC PATTERNS

Figure 6.4

The method of evaluating a typical HUB was a digital simulation of a type airport. This model has the capability of predicting delay based on certain basic input data. Thus, there was a wide range of possible options open for consideration. One important consideration involved the dual use of this model. The model may be used to predict delay for a particular airport and may also be utilized effectively to indicate satisfactory design analysis of several airports servicing a HUB (See Figures 6.5 and 6.6).

The quantative measures selected to gauge an air traffic control system were delay, aircraft mix (by type), operations (total), and operations per hour yearly average. These were defined as follows:

(1) Measure of Effectiveness: Delay

(a) Delay is defined as differential of time between landing of single aircraft (only one in the system) and landing of any aircraft when the system is operating with other aircraft.

(b) Delay is measured in minutes.

(c) Delay is considered, for this analysis, a yearly average per aircraft (irrespective of type).

(2) Measure of Capacity: Operations/Hour

(a) Operation is defined as a landing or a takeoff.

(b) Operations/Hour was compured on a yearly average basis. It is average take offs/landings per hour.

(3) Model. (See Model Discussion Section 6.4 and Figure 6.5) :

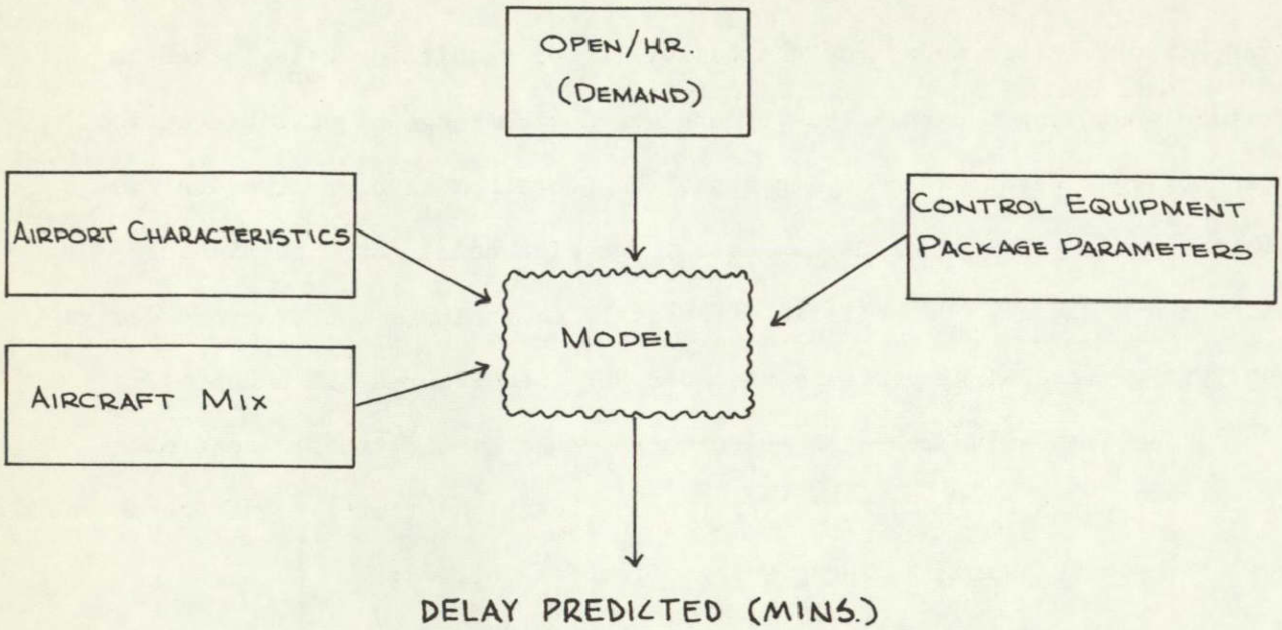
(a) Input: Airport Characteristics

Operations/Hour (demand)

Control Package Parameters

Aircraft Mix

(b) Output: Delay



DELAY MODEL

Figure 6.5

(4) System Analysis (See Figure 6.6)

(a) Input: Airport Characteristics

Airport Congifurations Under Consideration

Demand

Delay Criteria (Maximum Acceptable Delay)

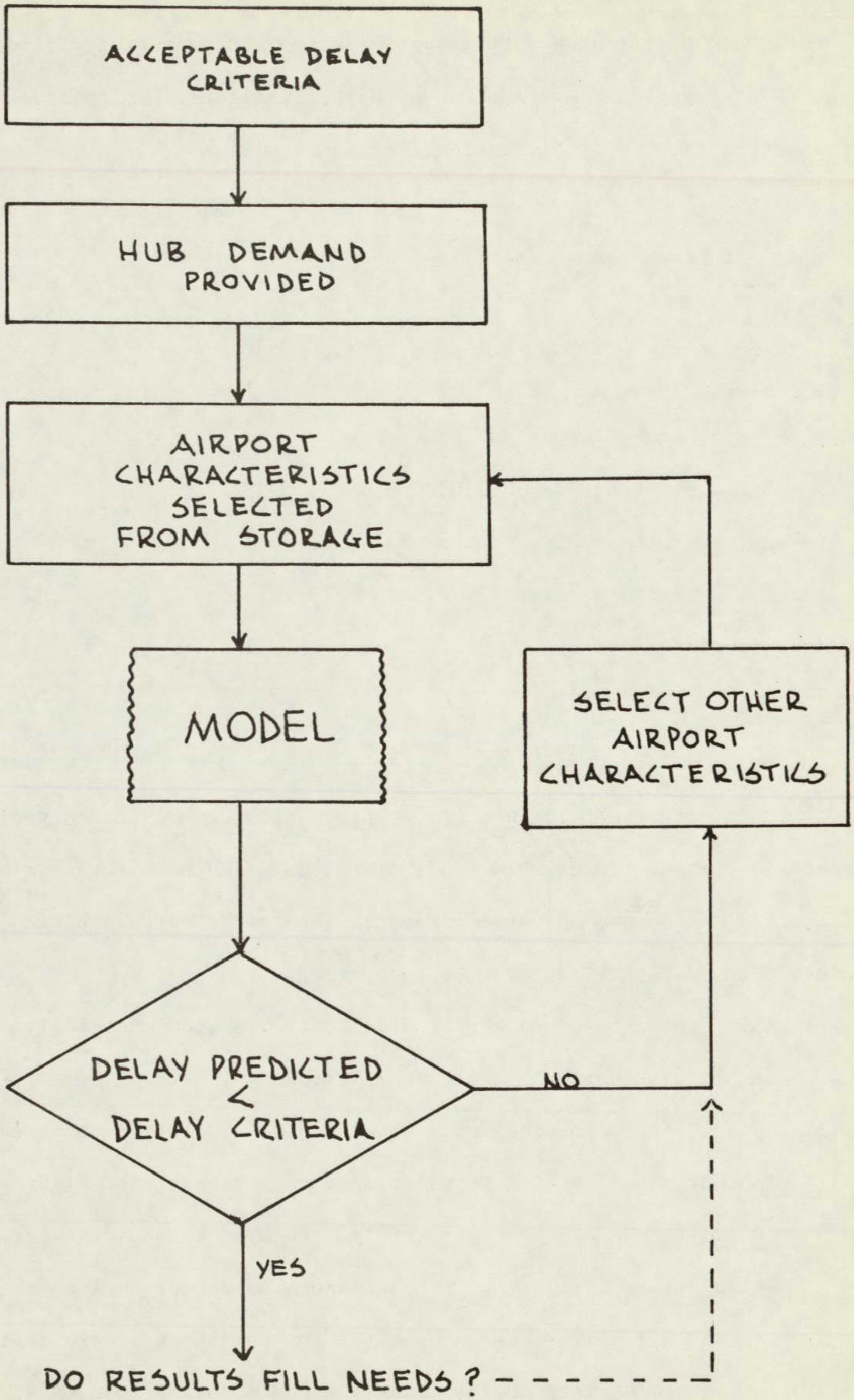
Control Package Parameters

(b) Output: Delay

Recommended Airport Configuration

Total Cost

The dual capability of the dealy model facilitates consideration of many alternative equipment and facility packages. Each package may be evaluated independently under various system demand conditions (Operations/Hour). This method allowed ordering of each package relative



SYSTEMS ANALYSIS OF DELAY

Figure 6.6

to all others and facilitated both suboptimization and sensitivity studies of system (HUB) reaction to variations of specific air traffic control model parameters (see Model Discussion, Section 6.4).

The aircraft classifications utilized were for the purpose of establishing aircraft mix. These classifications were as follows:

TYPE	CLASS
Large Turbo jet	1
Four-engine propeller transport	2
Two-engine transport (8000-36000 lbs)	3
Two-engine transport and high performance single-engine aircraft (including STOL)	4
Single-engine aircraft	5

6.2.3 Analysis

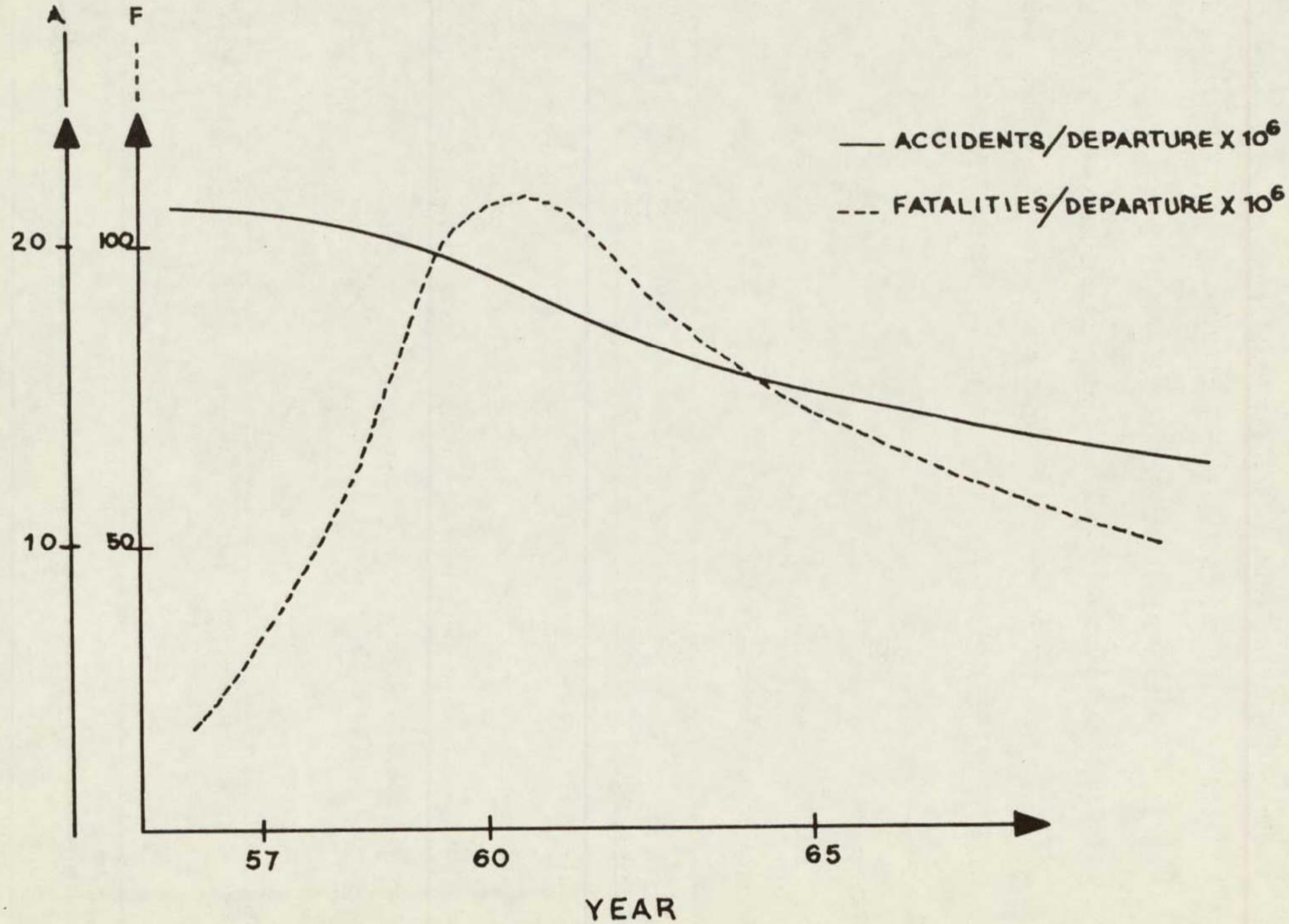
6.2.3.1 Safety

An air traffic control system must safely provide adequate capacity for a specific demand. This implies airborne separation of aircraft since no two aircraft may occupy the same airspace. Therefore certain basic safety constraints and considerations must be understood.

(1) All components of an air traffic control system must fully comply with current safety requirements.

(2) Anticipated components must provide a safety level equivalent to that anticipated from existing safety trends (See Figure 6.7).

(3) Safety trends are more accurately portrayed by accident/fatality vs. departure statistics. The exposure to danger during an air trip is not uniform throughout the trip and thus a trip of long length and no intermediate landings could possibly be safer than

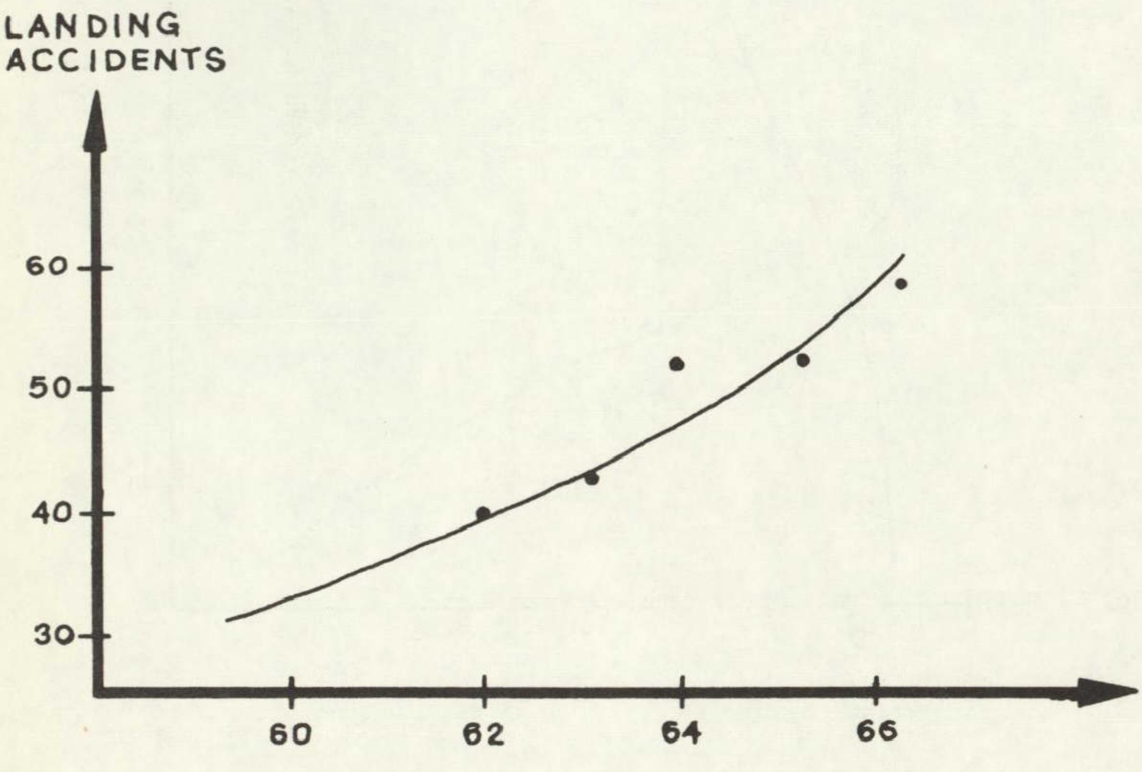


SAFETY TRENDS

Figure 6.7

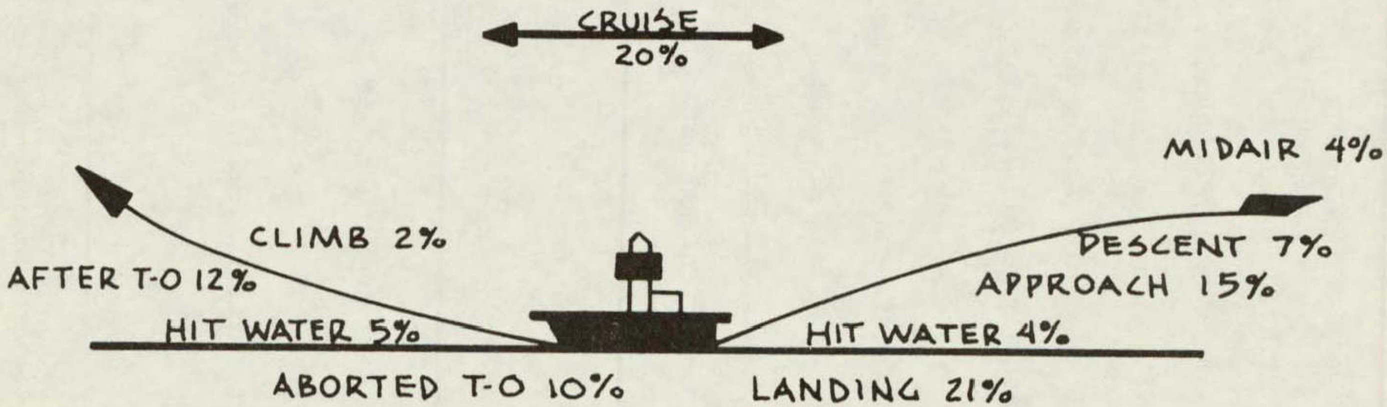
one of short duration but with several landings and take-offs.

(4) A primary purpose of air traffic control is that of safely meeting demand. The emphasis on safety, statistically indicated rise in landing accidents, (See Figure 6.8), and recognition that a very high percentage of all accidents occur in the terminal area have all generated a need for a collision avoidance system (See Figure 6.9). Such a system is not now in existence. Discussion and consideration of collision avoidance is outlined in Appendix 6-E.



THE RISE IN LANDING ACCIDENTS

Figure 6.8



ACCIDENT OCCURANCE
1953-1968

Figure 6.9

6.2.3.2 Performance Improvement

There are many techniques available for improvement of the control of air traffic over present performance levels. The more important of these include:

(1) Preassigned Departure/Arrival Times: This technique requires considerable computer assistance. It consists of second-by-second scheduling and flight progress monitoring to insure that takeoffs and arrivals are exactly on schedule. The NAS packages will eventually provide a limited capability in this area (See Appendix 6-C, National Airspace System). This technique was not considered in this analysis.

(2) Speed Class Sequencing: Aircraft of similar speed capability are grouped together in an approach sequence to reduce intervals between aircraft. This technique is politically and economically difficult to implement and was not considered.

(3) Path Stretching: This technique is the procedure of assigning faster aircraft longer approach paths to have them arrive in coincidence with slower aircraft. Path stretching is difficult to control since each operation must be hand controlled and large numbers of simultaneously occuring cases of path stretching reduce safety margins. Path stretching was not considered.

(4) Computer Aided Approach Sequencing (CAAS): Aircraft are assigned times and positions at which they may depart the holding pattern based on their turn to land and their velocity profiles. CAAS is a worthwhile technique for further consideration but was not considered.

(5) Separation Reduction (SR): This technique limits the distance (time) of aircraft separation. The technique was considered. It appeared initially the most promising because there were many obvious ways of implementing SR. Further it appeared to be the technique that would result in the most improvement.

The delay model input parameters were basically time separation parameters for a pair of aircraft. The parameters represent separation of two aircraft (in seconds) for the possible combination of landings and take-offs. The time separation parameters are (see Figure 6.10).

(1) T Time from Departure "start to roll" down the runway of the first aircraft to "start to roll" of the second aircraft (Departure-Departure).

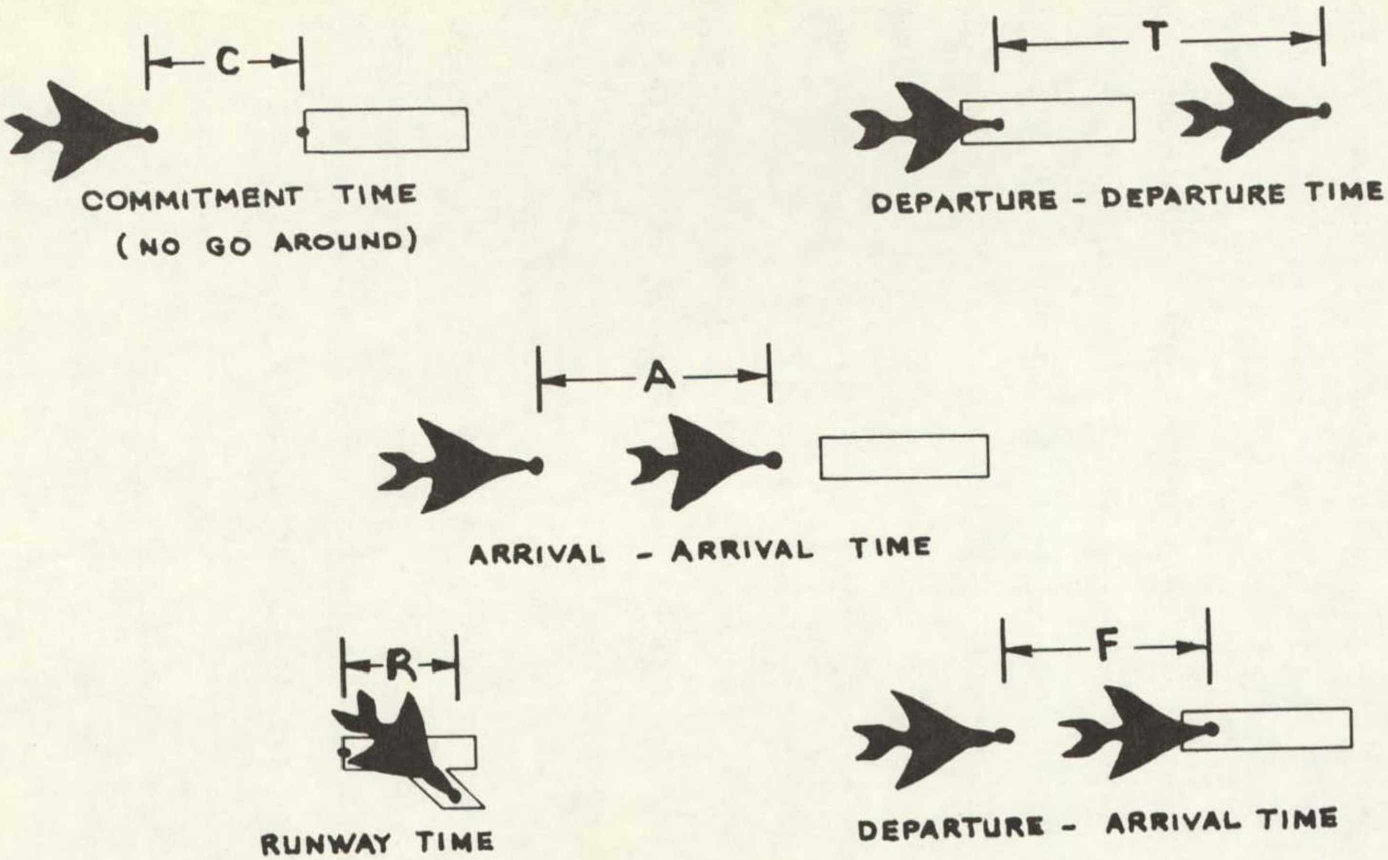
(2) F Time from Departure "start to roll" to arrival "over commitment" (point on final approach beyond which the aircraft must "touch down") (Departure - Arrival).

(3) R Time of runway occupancy from "over threshold" (over approach end of the runway) to slow down to a ground speed of 25 MPH. This speed was considered slow enough for aircraft to safely turn on to runway turn-offs.

(4) C Time from "commitment to land" to "over threshold" for an aircraft.

(5) A Time of separation for an arrival followed by an arrival (Arrival - Arrival).

The effect of separation reduction may be observed in two ways. First, a specific item of equipment or facility modification may be substituted into the system. This infers a change in one or more of the delay model input parameters (time separation parameters).



TIME SEPARATION PARAMETERS

Figure 6.10

Second, incrementing each time separation parameter, while holding all others constant, may reveal the most "sensitive" parameter. This infers that a change of the most "sensitive" parameter will result in the most system improvement. The change necessary for the "sensitive" parameter may result from appropriate equipment and for facility modification.

The analysis utilized in this study consisted of selection of three typical equipment packages that were based on (1) present capability, (2) 1975 capability and (3) 1980 capability. The delay model was utilized, in conjuction with the three equipment packages, to predict delay. The consideration of each package also involved, for each HUB and demand condition, selection of an airport configuration and comparison of the predicted delay with each HUB delay criteria. When the predicted delay exceeded the HUB delay criteria, another airport configuration was considered. Concurrently with this computer analysis, and built into the computer program, cost appraisals were accumulated.

6.3 Equipment Evaluation

6.3.1 General

Equipment evaluation was concerned primarily with selection and evaluation of equipment for each of the three packages necessary for safe and efficient air traffic control (ATC). Since this equipment varies significantly as a function of the amount and type of traffic into and out of an air terminal, only those terminals with at least 24,000 itinerant operations per year and between 20,000 and 50,000 instrument flight rule (IFR) operations per year were considered. The 24,000 itinerant operations per year qualify an air terminal for an Air Traffic Control Tower (ATCT) and the 20,000 - 50,000 IFR operations per year qualify the air terminal for a Terminal Radar Control (TRACON) facility. Itinerant operations, as used in this context, were comprised of all planes that depart for

destinations elsewhere or that arrive from departures elsewhere. Typical air terminals within these bounds include the ones at Atlanta, Georgia; Memphis, Tennessee; and Jacksonville, Florida. A single runway configuration and Instrument Flight Rules (IFR) conditions were assumed.

The consideration of ground equipment for ATC was accomplised by examining three different configurations of typical equipments. These three equipment "packages" were designated as (1) present equipment including an ASR-4 Radar and standard Instrument Landing System (ILS), (2) an ASR-7 Radar, equipment in Phase A of the National Airspace System (NAS) plan, and a standard ILS, and (3) equipments in (2) plus an improved ILS. The initial portion of this part of the report will provide a brief description of the various equipments and identify those performance parameters which were pertinent to improved ATC. This description and identification will be provided for each of the three equipment packages. The second portion of this section will stipulate values for various system level performance parameters (time separation parameters) which can be modeled in a computer program to determine optimum equipment configurations. Systems level performance parameters were those that involve ground equipment, aircraft class, and terminal runway configuration. Optimum equipment configurations were those that provided minimum delays to air traffic. The final portion of this section consists of "playing" the equipment performance parameters against the system level performance parameters in such a way as to reveal improvements (or decreased delays) possible in the ATC system. These improvements will be identified as a function of the three equipment packages.

6.3.2 Equipment Performance Parameters

6.3.2.1 Equipment Package No. 1

Equipments in this package are intended to represent those in present use; however, such equipments are large in number and vary widely from one installation to another. Consequently, only those equipments likely to (1) significantly influence traffic delays and (2) be common to a majority of the installations are considered. With this in mind, the equipment in Package No. 1 consisted of:

(1) An ASR-4 Radar System

(2) A Standard FAA Instrument Landing System

6.3.2.2 Equipment Description

The ASR-4 System consists of a radar antenna, transmitter, receiver, displays, performance moitors, and control/distribution units. Except for the antenna, major components of the system are duplicated to provide redundant operation. Maximum operational capabilities of the ASR-4 are approximately 54 nautical miles in range; 30,000 feet in altitude. Aircraft range and azimuth position are displayed to the controller on Plan Position Indicators (PPI's). The system is usually located at two different sites, one designated the radar site and the other the indicator site. The transmitter, receiver, antenna and performance monitors are typically located at the radar site while the displays and remote control units are typically located at the indicator sites. The two sites are connected via either microwave data link or underground cables. Separation between the two sites is limited to approximately two miles when underground cables are used because of signal attenuation in the cables.

The ASR-4 System operates in the S-band frequency range (2.7 to 2.9 gigahertz) with a peak power output of 450 kilowatts. The antenna scans a 360 degree azimuth plane with a radiaton pattern that is 1.5 degrees in

in the horizontal plane and cosecant squared 5 degrees in the vertical plane. The transmitter uses a magnetron signal source and has one of three standard pulse repetition frequencies chosen at the time of manufacture. The receiver provides a Normal and a Moving Target Indicator (MTI) mode of operation. Normal reception detects and processes all reflected signals within the system range. MTI reception cancels stationary target echoes enhancing moving target echoes. Both receiver modes use an amplifier to increase the received signal strength.

A standard ILS is comprised essentially of an Outer Marker Beacon and a Very High Frequency (VHF) localizer. The Outer Marker is located 4 to 7 miles from the end of the runway and is identified by its 400 cycle modulation. The glide slope at the outer marker is approximately 2920 feet in width, 475 feet in height, and 2.5 degrees above the horizontal. Lateral deviation from the center of the glide slope path is determined by a cockpit indication of either 90 or 150 Hertz modulation. The Middle Marker Beacon is modulated with a 1300 Hertz signal and is located approximately 4500 feet from the end of the runway. At this Beacon, the glide slope path is approximately 915 feet in width, 5 feet in height, and 200 feet above the ground. Both of the Marker Beacons operate at 75 megahertz with an output power of approximately 2 watts. The VHF localizer is at the end of the runway and radiates 100 watts in the 108.1 to 111.9 megahertz frequency range.

6.3.2.3 Performance Parameters

The following represent the major performance parameters for the ASR-4 Radar System:

(1) Range Accuracy - Targets are shown within 2 percent of their true range provided they are at a range in excess of 10 percent

of the sweep range in use. In no case will the absolute error be over 2 percent of the true range.

(2) Azimuth Accuracy - The maximum angular error in the position of targets is ± 1 degree.

(3) Range Resolution - The system distinguishes between two different targets in the same class separated by a distance of 1300 feet on the 40 mile range.

(4) Azimuth Resolution - Targets of the same class, equidistant from the antenna, and separated by approximately 2.25 degrees are indicated as separate targets provided they are at a range in excess of 10 percent of the sweep range in use.

(5) Maximum Range - Targets 54 nautical miles from the antenna are detected.

The major performance characteristics for the standard ILS are:

(1) Glide Slope Approach Path - A single glide slope approach path is provided.

(2) Aircraft Position Indication - The precise determination of aircraft position is indicated within a ± 4 degree beam for both the localizer and glide path. This beam is measured relative to the runway centerline.

6.3.2.4 Equipment Package No. 2

Equipments in this package are intended to represent those in current use plus those whose utilization and installation are already planned. Package No. 2, therefore, contains all of the equipments in Package No. 1, except the display units, plus those equipments identified in Phase A of the NAS. As with Package No. 1, equipments in Package No. 2 also vary widely from one installation to another; therefore, only equipments likely

to (1) significantly influence traffic delays and (2) be common to a majority of the installations are considered. Equipments in this package, then, are :

(1) An ASR-7 Radar System

(2) Equipment identified in Phase A of the NAS plan.

(3) A standard FAA ILS

6.3.2.5 Description

The ASR-7 Radar System has the same basic components and redundant operational features as does the ASR-4 System described in Section 6.3.2.2. All circuitry uses solid state devices and construciton concepts are almost completely modular. The operational range of the ASR-7 is approximately 90 nautical miles and 50,000 feet altitude. Aircraft range and azimuth are indicated on 16 inch cathode ray tube PPI displays. Frequency range and peak power capabilities are essentially identical to the ASR-4 systems.

Equipments comprising Phase A of the NAS plan are a Common Digitizer (CD), a digital data communications (DACOM) receiver and transmitter, a data receiver group (DRG), a central computer complex (CCC), a computer display channel (CDC), computer update equipment (CUE), appropriate displays, and a system maintenance monitor consol (SMMC). The broad objective that installation of these equipments will satisfy are:

(1) Automatic transfer, processing and updating of flight information.

(2) Automatic establishment and maintenance of radar identification. of aircraft

(3) Automatic display of altitude and flight level information with aircraft position.

(4) Provide a computer processing capability to serve as the basis for future addtion of automatic improvements to ATC.

The CD equipments take raw radar and beacon data and convert it to digital messages to be transmitted to an ATC center. These messages are then transmitted over telephone lines by the DACOM equipments. The DRG receives the CD message from DACOM equipments, provides message synchronization and decodes the message labels for routing the messages to the desired control centers. The CCC receives the incoming messages and (1) prepares for distribution of flight plans, and (2) updates radar information on display equipments. Data from the CCC and requests for review by the controller is displayed on the CDC equipments. A command link between the computer and controllers is provided by the CUE to assure that the desired flight data is processed. The status operational mode and configuration is usually displayed by means of monitors provided as a part of the SMMC equipments. All of these equipments function together to provide a high degree of automatic data handling and processing primarily for enroute ATC.

6.3.2.6 Performance Parameters

The following represent the major performance parameters for the ASR-7 Radar System:

(1) Range Accuracy - Targets are shown within 2 percent, or 0.05 inches on the display whichever is greater, of their true range provided they are at a range in excess of 10 percent of the sweep range in use.

(2) Aximuth Accuracy - The maximum angular error in the position of targets is 1 degree.

(3) Range Resolution - The system distinguishes between two different targets in the same class separated by a distance of 821 feet.

(4) Azimuth Resolution - Targets of the same class, equidistant from the antenna, and separated by approximately 1.5 degrees are indicated as separate targets provided they are at a range in excess of 10 percent of the sweep range in use.

(5) Maximum Range - Targets 80 nautical miles from the antenna and 5 square meters in size have been detected.

Performance parameters of the equipments to be implemented during Phase A of the NAS plan are not directly relatable to the system level performance parameters; consequently, they will not be delineated here. This does not imply that these equipments do not improve ATC. Instead, the improvement is somewhat intangible in-so-far as the relationship to the system level performance parameters established in Section 6.3.3.

The ILS performance parameters are identical to those listed in Section 6.3.2.3 since the same ILS is used in this equipment package.

6.3.2.7 Equipment Package No. 3

Equipments in this package include those in Phase A of the NAS plan, the ASR-7 Radar System, plus some equipments virtually certain for future installation. These additional equipments are ones which are capable of significantly affecting traffic delays. The following specific equipments are contained in this package:

(1) An ASR-7 Radar System

(2) Equipments included in Phase A installations of the NAS plan

(3) An improved ILS system

6.3.2.8 Description

A brief description of the ASR-7 Radar System and the NAS plan Phase A equipments was provided in Section 6.3.2.5.

6.3.2.9 Performance Parameters

Performance parameters for the ASR-7 Radar System and the Phase A equipments in the NAS plan were presented in Section 6.3.2.6.

The major performance characteristics for the improved ILS are:

(1) Glide Slope Approach Path - Approach paths for curved and/or dogleg approaches both in the vertical and lateral directions are provided.

(2) Aircraft Position Indicator - A precise determination of aircraft position is indicated within a $\pm$ 40 degree lateral beam from the runway centerline and a 15 degree vertical beam above the horizontal.

6.3.3 System Level Performance Parameters (Time Separation Parameters)

In order to evaluate the effectiveness of various ground equipment configurations, it was necessary to specify pertinent performance parameters which can be independently or collectively varied in a computer model of the ATC system. These parameters must be ultimately related to traffic delay since this was the ultimate criteria established for effectiveness of the ATC system. In establishing these parameters, a single runway IFR conditions and a single approach and departure route were assumed.

Five basic performance parameters were identified as necessary for the computer model inputs. These parameters were defined as:

(1) Parameter T - Departure Followed By Departure Time. This is the average time interval between clearance to takeoff or start roll for two successive aircraft on the same runway. For aircraft of the same general class published data indicates that the average value of T is approximately 90 seconds.

(2) Parameter F - Deaprture Followed by Arrival Time. This is the average time interval required to release and clear a departing aircraft in front of an arriving aircraft. Wide variations in the average value of F result because of its being a function of aircraft class. Published data indicates that a value of approximately 65 seconds is reasonable for aircraft of the same class. The minimum 3 mile spacing imposed by current regulations is basic to the establishment of 65 seconds as a value for F.

(3) Parameter R - Runway Occupancy for Arrivals. This parameter has a dual definition as follows: (a) the average time interval between "over threshold" and "off runway" for the first aircraft, and (b) the average time interval between arrival and departure of two aircraft in terms of "over threshold" and "off runway" of the arriving aircraft. Establishment of an average value for R was particularly difficult because of its variations as a function of aircraft class, landing rate, runway turnoffs, altitude, weather conditions, etc. However, published data normally establishes R as approximately 52 seconds.

(4) C-Commitment Interval for Arrivals. This parameter represents the average time interval between the commitment to land and "over threshold" of an arriving aircraft. Published data indicated that C is approximately 28 seconds for large aircraft and 12 seconds for very small aircraft. Factors such as reaction time, arrival population, etc., influence C.

(5) A - Minimum Time Interval Between Consecutive Arrivals. The factor that results when R and C are added to observed inter-arrival time gaps represents the parameter A. These time gaps are commonly inserted by the pilot/controller to provide a buffer

or safety margin to offset any misjudgements that may have occurred. The parameter value varies significantly as a function of both aircraft mix and landing speeds, but an average time interval of 168 seconds is consistent with published data.

6.3.3.1 Performance Improvements

6.3.3.1.1 Parameter C

The IFR conditions initially assumed require that a pilot be assured of a landing somewhat earlier in the approach than would have been necessary under VFR conditions. Also under VFR conditions, the pilot can quite accurately decide for himself whether or not he is in a position to continue his landing procedure or to go around. IFR conditions, however, pose a substantially different problem since the poor visibility and weather demand that the pilot fly by his instruments. As a consequence of the IFR conditions, the major burden of establishing a commitment-to-land-- and thereby the time interval C -- falls on the controller. To establish C with a reasonable trade off between safety and number of landings per time interval, the controller is heavily dependent on the ground equipment at his command. Obviously, the more capability the ground equipment possesses, the smaller the value of C can be.

The pertinent improvements of Equipment Package No. 2 over Package No. 1 were as follows:

(1) range accuracy - 0%

(2) azimuth accuracy - 95%

(3) range resolution - 58.4%

(4) azimuth resolution - 46%

(5) glide slope path - 0%

(6) aircraft lateral position -0%

(7) aircraft vertical position - 0%

(8) range 38%

An additional consideration was the fact that the NAS plan Phase A equipments should improve the ability to group arriving aircraft according to speed and class categories as well as landing velocity profiles. When all of these factors were collectively considered, it was judged that the parameter C would be reduced by 13% when Equipment Package No. 2 was implemented instead of Package No. 1. No additional improvement was evident when Package No. 3 was considered relative to Package No. 2.

6.3.3.1.2 Parameters T and F

The factors influencing the parameters T and F were essentially the same, and consequently, the two parameters were considered simultaneously. IFR conditions demand that aircraft spacing be rather rigidly enforced, sometimes quite a long way from the runway. The current FAA regualion requires a minimum spacing of 3 miles between successively arriving aircraft. This limit is thought to be based primarily on the ability of present radars to "touch" the skin of an aircraft. Both T and F are significantly influenced by arrival/departure populations and routes. Additionally, the ability to accurately and safely maintain precision approach paths becomes a primary consideration in the parameter T. A definite relationship between T and F -- and C as well-- exists as a function of the controller. He has the primary responsibility of deciding how far an arriving aircraft can be from touchdown and aircraft departures still be permitted. A 2 mile distance from touchdown is typical, and is obviously related to the commitment-to-land point, and thereby to C. The controller's ability to safely and efficiently make this determination is strongly influenced by ground equipment capability.

Based on the precent improvements of Equipment Package No. 2 over Package No. 1 as given in Section 6.3.3.1.1 was judged that T could be reduced by 55% and F reduced by 11%. Equipment Package No. 3 offers the following improvements over Package No. 2: Glide slope path - 100%, aircraft lateral position - 90% and aircraft vertical position - 100%. Based on these capabilities, the parameter F could be reduced by an additional 26% when Package No. 3 is used instead of Package No. 2.

6.3.3.1.3 Parameter R

There is very little overall benefit to be realized from any configuration of ATC equipment that improves F, R, and C but is not capable of enchancing the runway movement of arriving aircraft. Yet, of all the literature surveyed, it appears that the research being currently funded generally ignores this important area. Published data specifically identifies this factor as being the major reason that when time intervals under all types of conditions are averaged, it takes 78 seconds to handle one aircraft operation. Additionally, this 78 seconds provides a limit of 46 operations per hour on a single runway. The time period of this course did not permit conception and evaluation of new equipment of even an evolutionary nature; however, the following broad ideas were explored but not in suffiecient depth to develop performance parameters:

1 A ground radar system with sufficient anti-clutter capability to make tracking and directing of aircraft possible on the runway.

2 The use of television cameras mounted on the nose wheel and with displays in the cockpit.

3 Runway configuration with essentially a continuous high speed turnoff such that the pilot could clear the runway just as soon as his aircraft speed would permit a gradual turn.

4 Electronic sensing devices mounted in the runway with suitable display of aircraft position ot the controller who would "map" out the rapid runway departure to be used by an arriving aircraft.

Since more of these possibilities were fully explored, it was assumed that R could be reduced by 10% for Equipment 2 and 3.

6.3.3.1.4 Parameter A

As indicated in (5) of Section 6.3.3, the parameter A varies directly with runway occupancy (R) and committment to land (C) time intervals. The values for these two intervals have been estimated in (3) and (4) of Section 6.3.3 as 52 and 28 seconds, respectively. Since the estimated value of parameter A was 168 seconds, the "buffer" or "safety margin" gap becomes 168-(52 + 28) or 88 seconds. It was this 88 second time interval to which improvement attention was directed.

Observations made at terminals such as Chicago's O'hare reveal that the average distance between large aircraft during the arrival phase is at least six miles. This separation and its corresponding time interval are twice the three mile limit imposed by the FAA. This is almost certain to exist until arrivals per hour exceed approximately 25. The excess three mile separation or "gap" is attributable to factors such as a pilot/controller confidence factor, pressure on pilot/controller as arrival rates increase, departures that must be sandwiched between arrivals, aircraft mix and class, any stacking or orbiting that has taken place, etc. Several of these factors are directly influenced by ground equipment capabilities. When the capabilities of Equipment Package No. 2 were compared to those of Package No. 1, it was determined that the 58.4% improvement in range resolution would permit the 88 seconds to be reduced to 66 seconds. An additional second reduction was possible in view of the improved capabilities

of Equipment Package No. 3 relative to Package No. 2 Thus, the 88 second time interval realized a total reduction of 26 seconds and the parameter A changed correspondingly.

6.3.3.2 Parameter Summary

The following table summaries the time separation parameters for the three equipment packages considered.

TABLE 6.1

Parameter	Equipment Packages		
	1	2	3
C	28 sec.	24.4 sec.	24.4 sec.
T	90 sec.	40.5 sec.	40.5 sec.
F	65 sec.	57.8 sec.	42.8 sec.
R	52 sec.	46.6 sec.	46.6 sec.
A	168 sec.	148 sec.	142 sec.

6.4 Controls Model

6.4.1 Introduction

The controls model presented here was the digital computer program used in conjunction with the other computer programs written by the other groups in the class to evaluate the cost and effectiveness of the air transportation system. There were five basic parts of the controls computer programs. The largest part of the program was devoted to determining the average air and gound delay experienced by aircraft entering or leaving the terminal area. Another part of the program determined the number of runways needed based on the delays calculated. After the number of runways were determined the land area required for the runwasy was determined the average taxi times were caluclated. The last part of the program determined the cost of the control system. Each of the five major components of the controls model will be explained in the following sections. A simplified block diagram showing operation of the complete control model is shown in Section 6.4.8.

6.4.2 Average Air and Ground Delay

The purpose of this portion of the model was to determine delay in the terminal area given a particular mix of aircraft and the total average operations per hour. An additional requirement was that the model be capable of analyzing certain critical parameters (A, R, C, T, & F). In order to accomplish this within the time constraints of the project a simple and easily programmable model was required. After an exhaustive search, it was decided that a model developed by the Airbore Instruments Laboratory (AIL) would be used. In order to use the selected model, numerous charts and graphs had to be programmed. Once this was accomplished, the delay

could easily be calculated. (For the delay submodel formulas, flow diagrams and computer printout see Appendix 6-A).

The model served well as a tool to determine delay in the present ATC system. However, the critical parameters can only be changed on a percentage basis which caused difficulty in assessing the merits of the various equipment packages. Using the percentage change approach, the model was quite satisfactory for analyzing the effect of individually reducing each critical parameter.

6.4.2.1 Model Operation

The computational process of this portion of the model was quite straightforward. Model inputs include number and placement of highspeed turnoffs, runway lengths, runway altitude, percentage mix, and total operations per hour (assume number of landings = number of takeoffs). The model outputs were air and ground delay in seconds. The basic portion of the program was a stored listing of the critical parameters. The value of each parameter varies according to the number of operations per hour. The program determined the average value for each parameter using probability theory and averaging techniques based on the aircraft mix. Once the final value for each parameter ahd been determined the delay was easily calculated using a series of delay formulas.

In order to determine the parameter sensitivity, each parameter (A, C, T, F, & R) was varied individually on a percentage basis (i.e. reduced from 100% of full value to 5% of full value). A plot of delay versus percent reduction reveals an indication of the relative sensitivity of each parameter.

In addition, it was required that the model possess a capability of

calculating delay for each of three different ATC equipment packages. The only feasible way of accomplishing this was to introduce a percent reduction in each parameter on a judgement basis after analyzing the effectiveness of each equipment package. This was not an ideal method. However, it does give an indication as to the merits of each package.

In general, it was felt that the model was quite effective for determining delay of the present day system and future systems if the critical parameters can be reduced on a percentage basis.

6.4.2.2 Capabilities & Limitations

The model was capable of computing air and ground delay as the number of operations per hour was varied, computing air and ground delay as each critical parameter was varied, and computing air and ground delay for each of three different packages.

There are a number of limitations to the model in its present state. However, with some changes most of the limitations can be eliminated.

The limitations of the programs are listed below:

(1) Runway altitude was fixed.

(2) Runway length was fixed.

(3) Number & placement of high speed turnoffs was fixed.

(4) Handles only IFR conditions.

(5) Runway was fixed as a single runway with only one IFR departure corridor.

The limitations above can be eliminated with additional programming of charts and tables for each different type of runway configuration and weather conditions (IFR, VFR) expected. These limitations were not considered critical to the effectiveness of the model due to the fact that the comparison of parameter sensitivity was relative. The limitation does, however, the overall analysis due to the fact that only one runway configuration was considered. Given the time, a more sophisticated program could be generated which could consider a variety of runway considererations.

6.4.2.3 Suggested Improvements.

In order to more fully investigate the total air traffic control system to include various landing takeoff patterns, runway configurations, holding patterns, separation reduction, etc. a more general model must be developed. One such model could be generated using a general purpose computer language (GPSS). A model of this type could be used to analyze equipment improvements in a much more efficient manner. The only difficulty with a model of this type is the fact that it is difficult if not impossible to fast time simulate pilot & controller actions and reactions. This problem was alleviated using the AIL model because the parameters were actually measured at airports and the human reactions were incorporated in the parameters themselves.

6.4.3 Number of Runways

For each of the eleven cities in the system the number of operations per hour were supplied as input data by the routes model. The operations per hour as used here consider an operation as a takeoff or landing and also assume that the number of takeoffs were equal to the number of landings for any one city. Also, the operations per hour were the average number

of operations determined by assuming a completely flat arrival rate for 24 hours a day, seven days a week, and 365 days a year. For each city the fraction of the total operation per hour occupied by each type of aircraft was supplied. The number and type of airports at each city were also furnished as input data. It was prearranged that six cases would be considered. These six cases were outlined in part (A) of Section 6.2.1.

In order to determine the number of runways it was necessary to establish the maximum delay that would be allowed. This maximum delay was left as a variable such that the effect of its value on the effectiveness of the overall system could be evaluated.

To actually calculate the number of runways necessary, one runway was first assumed. If either the average ground delay or the average air delay exceeded the maximum allowable delay another runway was added. Additional runways would be added until an acceptable delay was reached.

When more than one airport in a city was available the following criteria was used to determine how the operation for a city would be divided among the airports. If only a CTOL airport was available all CTOL and STOL aircraft would be landed on the CTOL runways. If both CTOL and STOL runways were considered all STOL aircraft went to STOL runways and all CTOL aircraft went to CTOL runways. If more than one airport had STOL runways then the STOL arrivals were divided equally among the STOL runways, and the same was done for CTOL.

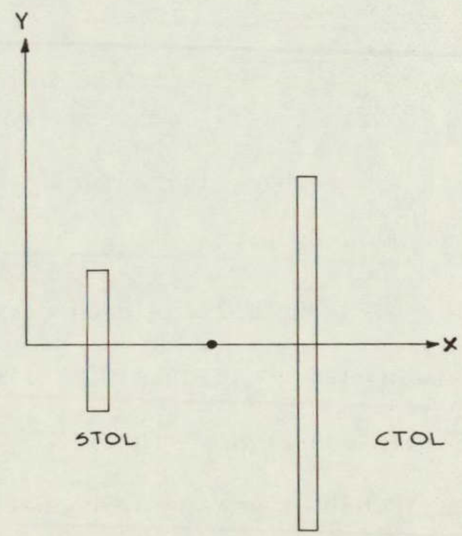
6.4.4 Runway Area

Since all the runways were assumed to be parallel, the calculations for the runway areas were simplified. It was assumed that the width of both STOL and CTOL runways was 150 ft. and the length of the CTOL runway was 10,000 ft. The lenght of the STOL runways was determined by the air-

craft group and was read as input data to this program. Both CTOL and STOL runways were assumed to be separated by 5000 ft. Then it was assumed that all runways could be contained in a rectangle and 1000 ft. added to each end of the runway rectangle. Also if more than one runway was considered the excess area between the runways was calculated. The excess area represented land between runways that could be used for the terminal building or parking. The excess area was considered to begin 1000 ft. from any runway. The 1000 ft. was assumed to be sufficiently large to account for taxi ways that would accompany each runway and would, of course, not be available for the terminal building or parking.

6.4.5 Area Taxi Time

The average taxi time was calculated in a simplified manner. Since it is difficult to determine exactly where to place the terminal building for any particular city because the land availability of that city, the terminal building was assumed to be located at the centroid of the runways. Figure 6.11 will help to illustrate how the centroid was calculated.



ASSUMED TERMINAL BUILDING LOCATION

Figure 6.11

This figure represents one CTOL and one STOL runway. Both runways were assumed to be symmetric about the x axis. The sum of the moment about the y axis was then calculated. A moment was considered to be the distance the runway was from the y axis times the length of the runway. The sum of the moment was then divided by the combined length of all the runways. The resulting number was the distance the centroid was located from the y axis. Because of symmetry, the x coordinate of the centroid always lies on the x axis. The taxi distance was then assumed to be a straight line between the centroid and the end of the runway. Assuming the taxi speed to be 25 mph, the taxi time could be estimated.

6.4.6 Air Traffic Control System Cost Model

The purpose of the ATC cost model was to determine the 1985-projected costs of the ATC system. These costs include the essential equipment, maintenance expenses, and salary expenses for three differnet package systems. Each package can be divided into 3 parts: airborne equipment, terminal equipment, and enroute equipment. In determining the cost the following assumptions were made:

(1) Eleven cities are involved.

(2) Two air route traffic control centers are involved.

(3) Two radar sites for each center exists.

(4) One radar site for each airport exists.

(5) Thirty five VOR/DME stations for each center exist.

(6) Salaries and maintenance expenses will rise 3% a year.

(7) The system will be operational in 1975.

(8) Terminals with 50,000 or more yearly operations are considered high activity terminals.

(9) Terminals with less than 50,000 yearly operations are considered medium activity terminals.

(10) The cost of individual pieces of equipment is an average cost; at each location the cost may vary.

The purpose of this model was to allow a rough comparison of the costs of each ATC system package being considered. (A flow diagram and computer printout of the cost model are shown in Appendix 6-B).

6.4.7 <u>The Cost of Equipment Packages</u>

To determine cost for the ATC system, three system packages are considered. Package 1 is the present (1969) system, the components of Package 1 are:

ASR-4 (Radar)

ILS Ground Equipment

VOR/DME Stations

VOR/DME Receivers

Altimeters

ILS Onboard Equipment

Transponder.

Package 2 contains NAS Stage A modifications, transponders with identification coding, ILS, and improved radar. Thus Package 2, includes:

NAS-A

SR-7

ILS Ground Equipment

Coder Transponders

VOR/DME Stations

Altimeters

ILS Aircraft Equipment

VOR/DME Receivers

Package 3 adds Area Navigation (R-NAU) capability and the proposed advanced ILS. This package includes:

Area Navigation Equipment

PVOR/DME

AILS (Advanced) Ground Equipment

Coder Transponder

ASR-7

NAS-A

AILS (Advanced) Air Equipment

VOR/DME

The following table contains the airborne and enroute costs of each package.

TABLE 6.2

* Millions of Dollars

Package Number	Airborne Costs* (Per Aircraft)		Enroute Costs* (Total System)	
#1	VOR/DME	.002	VOR/DME	10.500
	Altimeter	.001	ASR-4 Radar	2.720
	ILS	.010	Center Facilities	2.820
	Transponder	.002		16.040
		.015	Operating Cost/Yr.	1.395
#2	VOR/DME	.002	VOR/DME Station	10.500
	Altimeter	.001	ASR-7 Radar	4.400
	ILS	.010	NAS-A	7.478
	Coder Transponder	.008		22.378
		.026	Operating Cost/Yr.	1.795
#3	PVOR/DME	.003	VOR/DME Station	10.500
	Altimeter	.001	ASR-7 Radar	4.400
	AILS	.015	NAS-A	7.478
	R-NAV	.050		22.378
	Coder Transponder	.008		
		.088	Operating Cost/Yr.	1.795

The following table contains the terminal costs of each package.

Terminal Costs *

(Per Airport)

Package Number	High Activity		Medium Activity	
#1	Radar Tower	1.410	Radar Tower	1.108
	ASR-4	.680	ASR-4	.680
	ILS	.468	ILS	.468
		2.558		2.256
	Operating Cost/Yr.	.641	Operating Cost/Yr.	.559
#2	Radar Tower	1.410	Radar Tower	1.108
	ASR-7	1.100	ASR-7	1.100
	AILS	.500	AILS	.500
		3.010		2.708
	Operating Cost/Yr.	.661	Operating Cost/Yr.	.579
#3	Radar Tower	1.410	Radar Tower	1.108
	ASR-7	1.100	ASR-7	1.100
	Hermes	.500	Hermes	.500
		3.010		2.708
	Operating Cost/Yr.	.666	Operating Cost/Yr.	.584

* Millions of Dollars

Table 6.3

6.4.8 The Controls Model

A simplified flow diagram of the controls model computer program is shown in Figure 6.12. A detailed flow diagram of the delay submodel as well as an actual computer printout are shown in Appendix 6-A. The cost submodel flow diagram and computer printout are shown in Appendix 6-B.

6.5 Results and Conclusions

6.5.1 Results

The applications of the delay model for each equipment package are illustrated in Figures 6.15-6.18. The aircraft mixes considered were as follows (format is CLASS 1/CLASS 2/CLASS 3/CLASS 4/CLASS 5/ where classification of aircraft in Section 6.2.2):

(1) 0.0/0.0/0.0/1.0/0.0

(2) 0.6/0.0/0.2/0.2/0.0

(3) 0.2/0.0/0.6/0.2/0.0

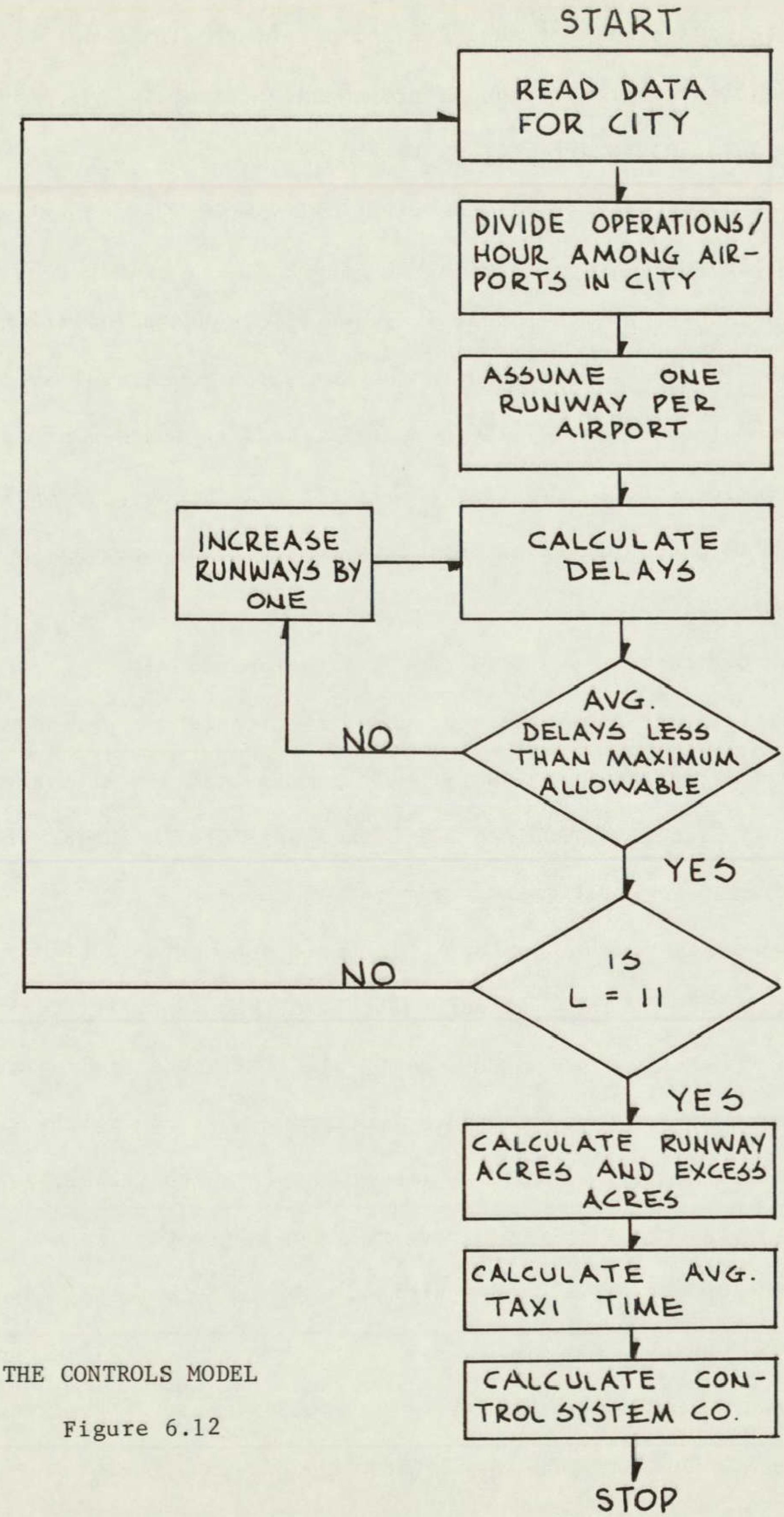
(4) 0.1/0.45/0.12/0.13/0.2

Note: STOL aircraft were considered CLASS 4 aircraft.

Each time separation parameter (T, F, R, C and A) was subjected to a sensitivity study. This was done with an assumed mix of 0.1/0.45/0.12/0.13/0.2 and considering equipment package 1. The purpose of this sensitivity study was to reveal those time separation parameters that were the most critical. Once the critical parameters are identified equipment and/or facilities might easily be substituted into the air traffic control system to reduce the delay times. The results of this sensitivity study are illustrated by Figures 6.13 and 6.14.

6.5.2 Conclusions

The following conclusions were determined from the graphs of Figures 6.13-6.18.



THE CONTROLS MODEL

Figure 6.12

(1) The use of equipment packages 2 and 3 in the delay model results in a substantial reduction in ground delay of up to 86%. And reductions in air delay of up to 80%.

(2) The STOL aircraft, as expected, performed much more satisfactorily where it operated at a 100% STOL airport.

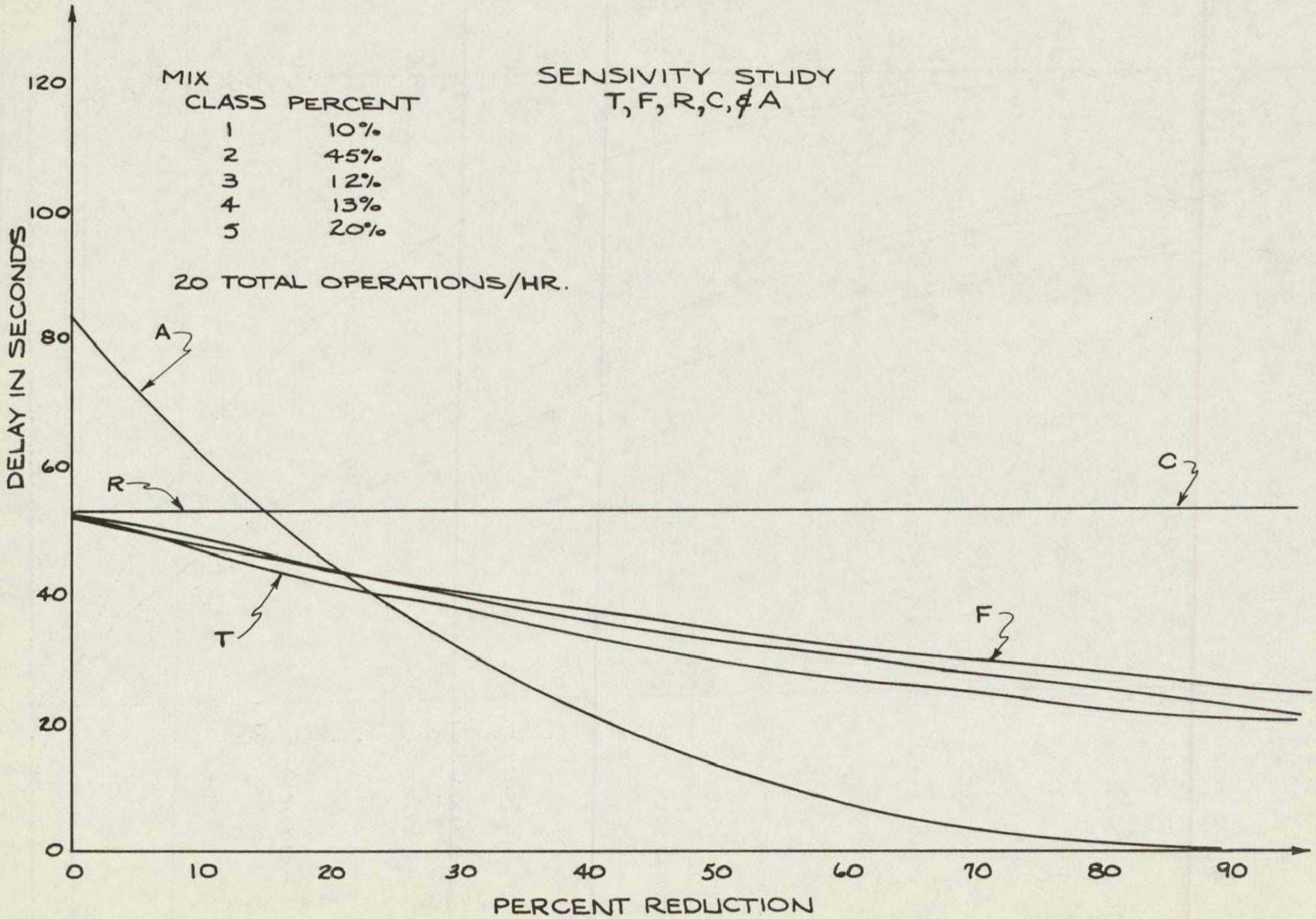
(3) The introduction of a runway or runways for general aviation use only may be expected to reduce delay for commercial aviation if general aviation aircraft are restricted to the use of only the general aviation runways. This reduction in delay results from elimination of slower aircraft in the queue waiting to land or take-off.

The sensitivity study of the five time separation parameters (T, F, R, C and A) revealed that A was the most sensitive separation parameter. Thus the greatest delay reduction may result from an improved Arrival-Arrival separation criteria. Additionally, this parameter might provide the most economically feasible method of reducing delay.

There are several important options which must be considered in conjunction with this study. These affect safety and the capability for continuous smooth operation (no surges) of an air traffic control system.

(1) The introduction of an advanced ILS system will contribute to an increased safety level. Further, the enhanced weather capability will contribute to reducing "surges" in the system.

(2) The development of related equipment will contribute to reducing "surges" Related equipments are such items as aircraft window defrosters, runway heating systems, advanced aircraft braking capability and fog dispersal devices.



SENSIVITY STUDY
T, F, R, C, & A
MIX
CLASS PERCENT
1 10%
2 45%
3 12%
4 13%
5 20%
20 TOTAL OPERATIONS/HR.
DELAY IN SECONDS
0
20
40
60
80
100
120
A
R
C
T
F
0
10
20
30
40
50
60
70
80
90
PERCENT REDUCTION

Figure 6.13

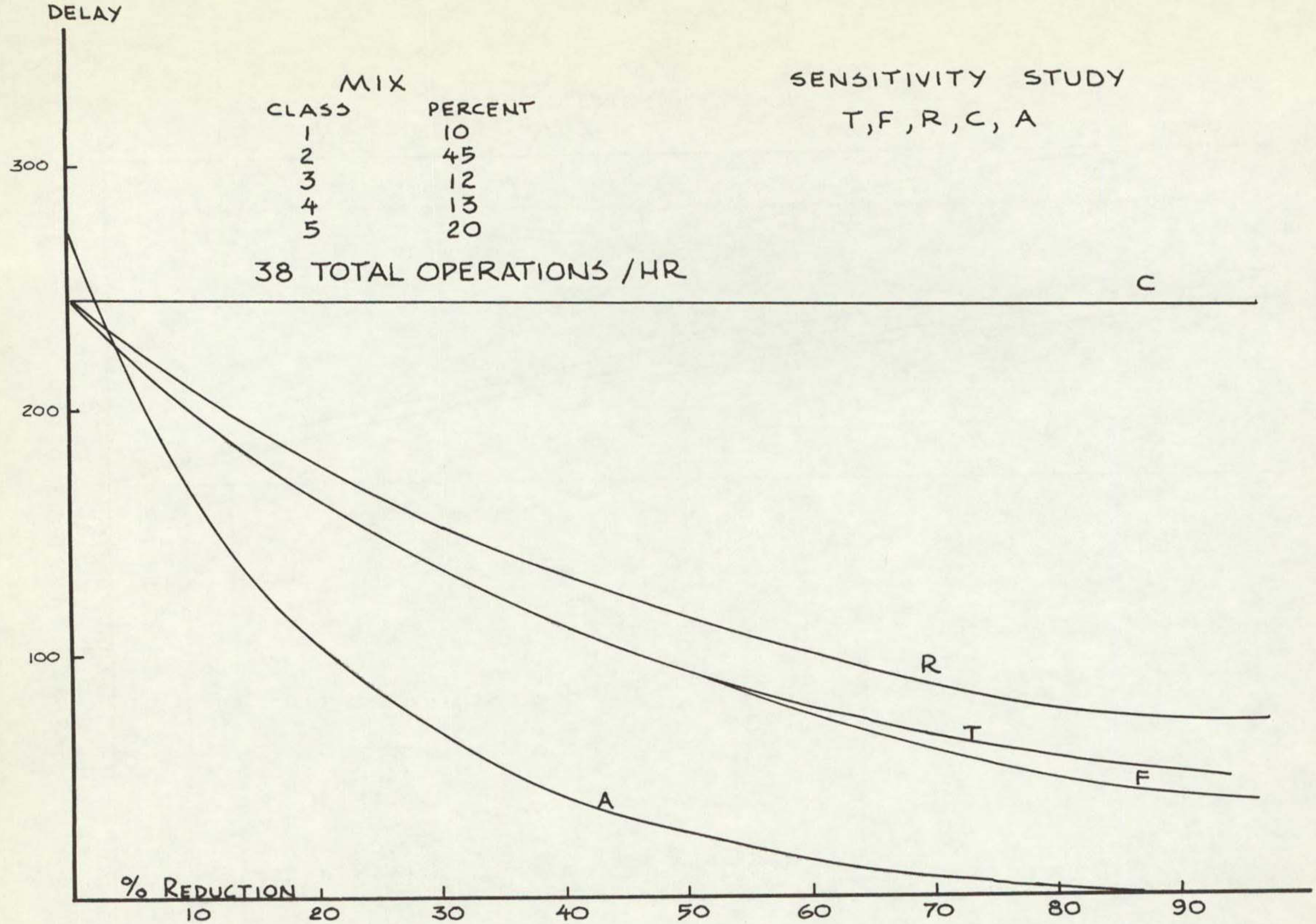

DELAY
MIX
CLASS PERCENT
1 10
2 45
3 12
4 13
5 20
38 TOTAL OPERATIONS /HR
SENSITIVITY STUDY
T, F, R, C, A
300
200
100
C
R
T
F
A
% REDUCTION
10
20
30
40
50
60
70
80
90

Figure 6.14

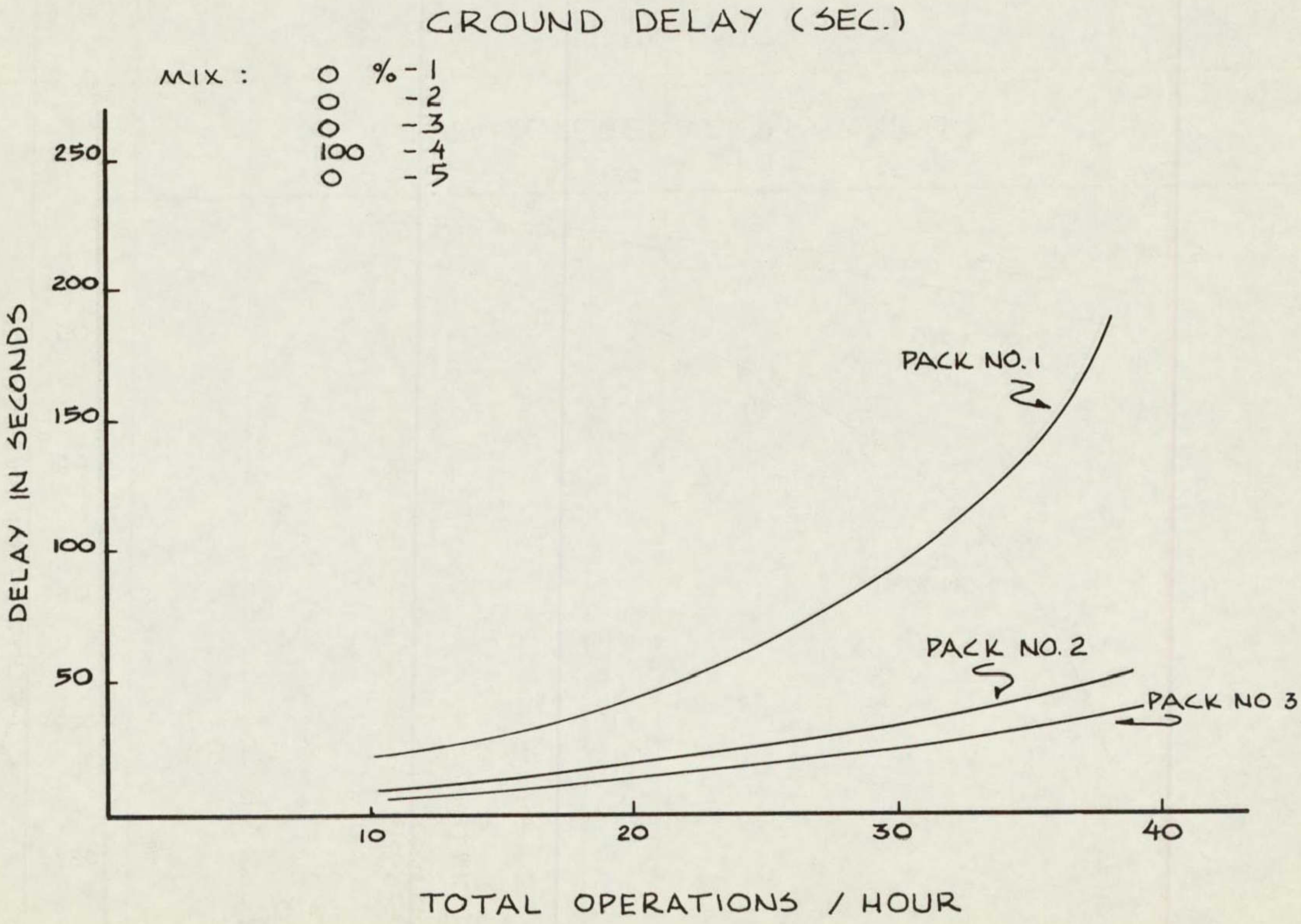

GROUND DELAY (SEC.)
MIX : 0 % - 1
0 - 2
0 - 3
100 - 4
0 - 5
DELAY IN SECONDS
250
200
150
100
50
PACK NO. 1
PACK NO. 2
PACK NO 3
10
20
30
40
TOTAL OPERATIONS / HOUR

Figure 6.15

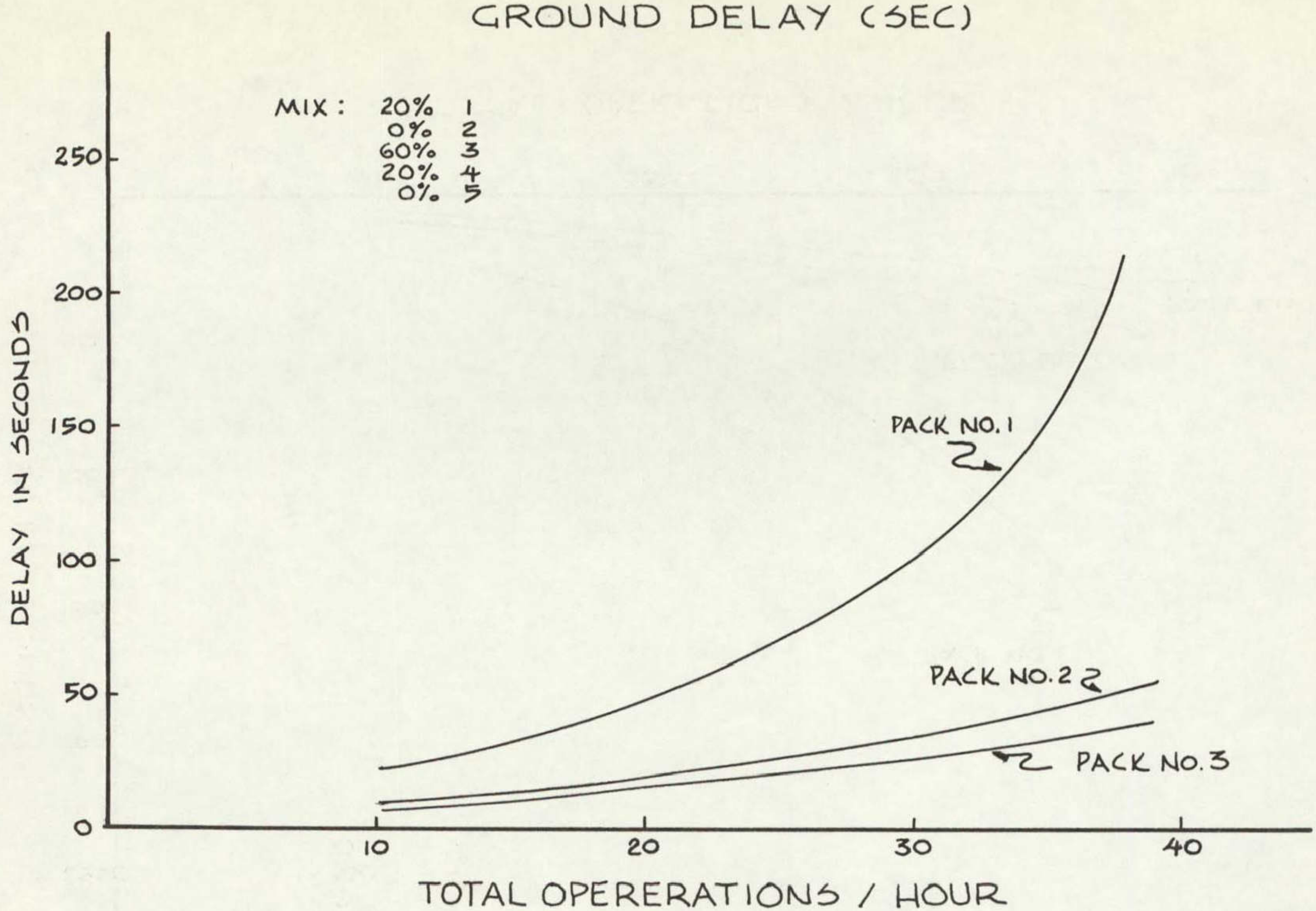

GROUND DELAY (SEC)
MIX: 20% 1
0% 2
60% 3
20% 4
0% 5
DELAY IN SECONDS
0
50
100
150
200
250
10
20
30
40
TOTAL OPERERATIONS / HOUR
PACK NO. 1
PACK NO. 2
PACK NO. 3

Figure 6.16

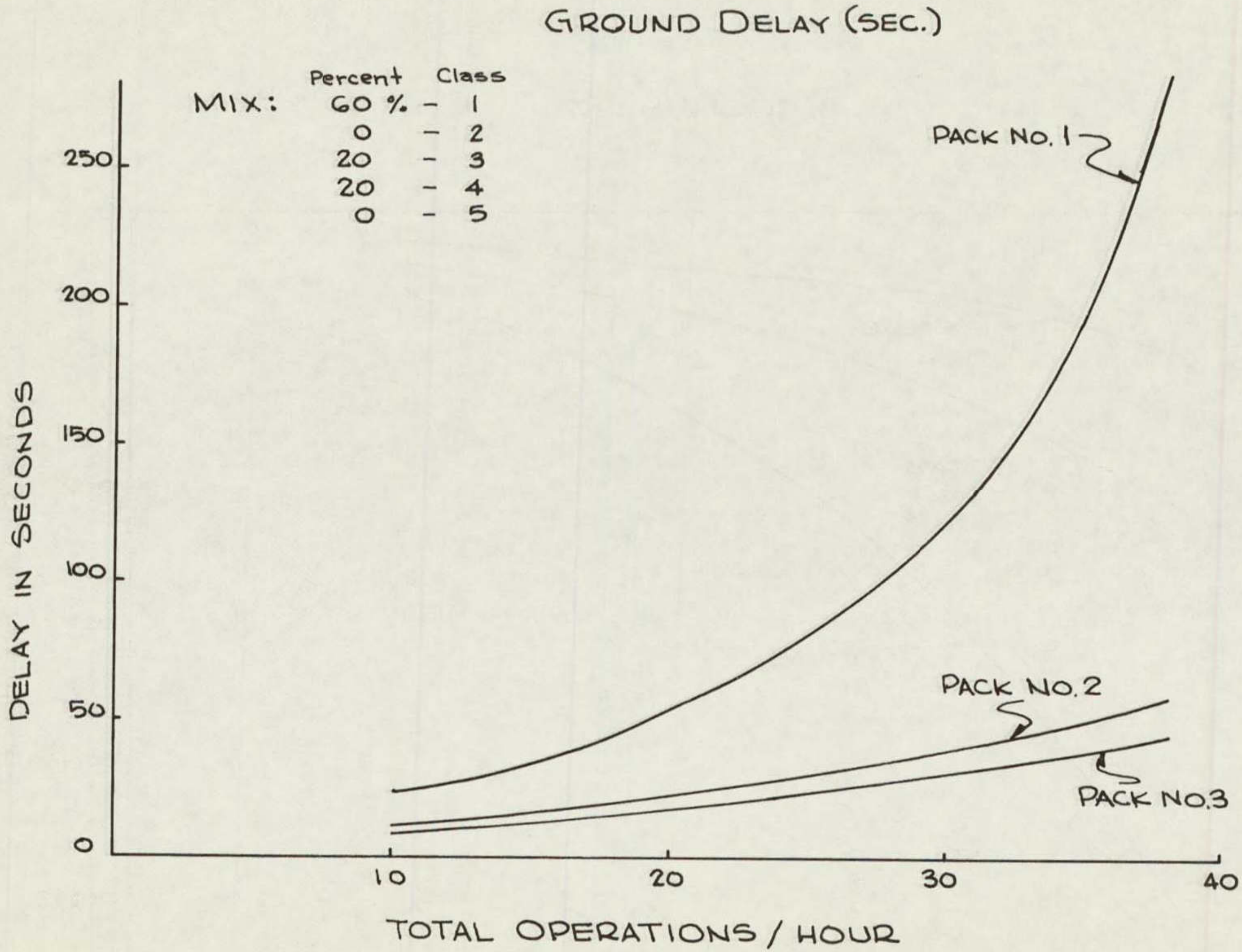
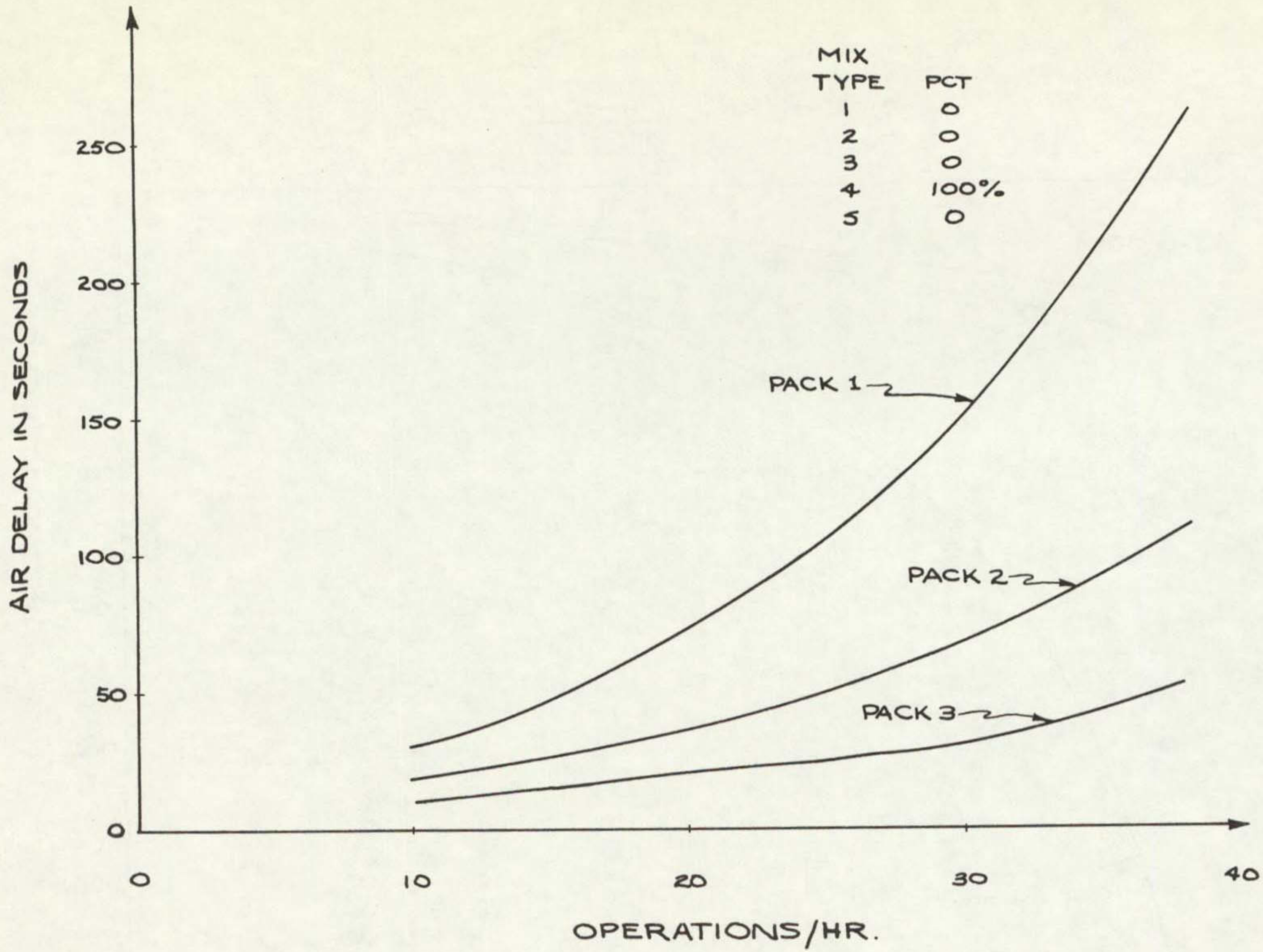

GROUND DELAY (SEC.)
Percent Class
MIX: 60 % - 1
0 - 2
20 - 3
20 - 4
0 - 5
PACK NO. 1
PACK NO. 2
PACK NO. 3
DELAY IN SECONDS
0
50
100
150
200
250
10
20
30
40
TOTAL OPERATIONS / HOUR

Figure 6.17



AIR DELAY

Figure 6.18

(3) Collision avoidance equipment can not presently be economically developed (See Appendix E).

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CHAPTER 7

COST-EFFECTIVENESS ANALYSIS

7.1 Introduction

A cost-effectiveness analysis is the fundamental building block for any systems engineering project. Simply stated, this analysis is responsible for examining each alternative system to establish the extent to which that system accomplishes the desired objectives and to estimate the requirements for men, material and equipment necessary to make that alternative a working reality. A statement of system objectives and a means of measuring these objectives are necessary before any effectiveness analysis can be done on the alternative systems. Requirements for men, materials and equipment can be summarized as a total cost for each alternative. Individual requirement break downs need only be considered when limitations are imposed on a specific resource.

7.2 Measure of Effectiveness

The function of any air transportation system is to supplement the national transportation system by providing adequate air transportation between all of the major cities of the continental United States. Two key words are drawn from this functional statement in order to define effectiveness - adequate and major cities. "Major cities" implies a large grouping of people who want to travel. The existance of this demand is fundamental to the approach taken here. "Adequate" implies a degree of acceptance. People who want to travel will select a mode based on the adequacy of available modes (here they take in account various factors like travel time, cost, mode frequency, service, ride comfort, and safety). If effective transportation modes are not available, expectations may be reduced for some types of trips while others will simply not be taken.

The approach used in this study is iterative in that forecasted travel demand is based on population, location, etc. and then each alternative system is forced to meet that demand. The level of service for each alternative is then evaluated for its effect on passengers. The more effective a system, the larger will be its share of the total demand. Total Revenue Passenger Miles (TRPM) was chosen as the measure-of-effectiveness for the air transportation system. A TRPM is simply one passenger flying one mile between his origin and destination. The distance used to calculate TRPM is the direct distance between origin and destination and not the actual distance flown. The revenue passenger miles for each route is calculated and then individual routes are summed to obtain the system's TRPM.

Certain characteristics of air transportation were felt to have a greater influence on air travel than other characteristics. It was the objective of the effectiveness model to account for these influences in air travel. Travel time, fare and frequency of service were considered of prime importance.

7.2.1 Travel Time and Fare

The forecast demand of air passenger traffic (See Chapter 3) does not take into account any additional traffic generated by airplanes and transportation modes from/to the airport with fares and travel times significantly lower or higher than the expected fare or travel time.

The total travel time is the time between leaving the actual departure point and the arrival at the actual destination (door-to-door time). The fare is defined as the total cost for a trip and includes, in addition to the ticket cost, the cost of traveling to the departure terminal and the cost of traveling from the destination terminal to the actual end point of the journey.

EFFECT OF TIME AND FARE

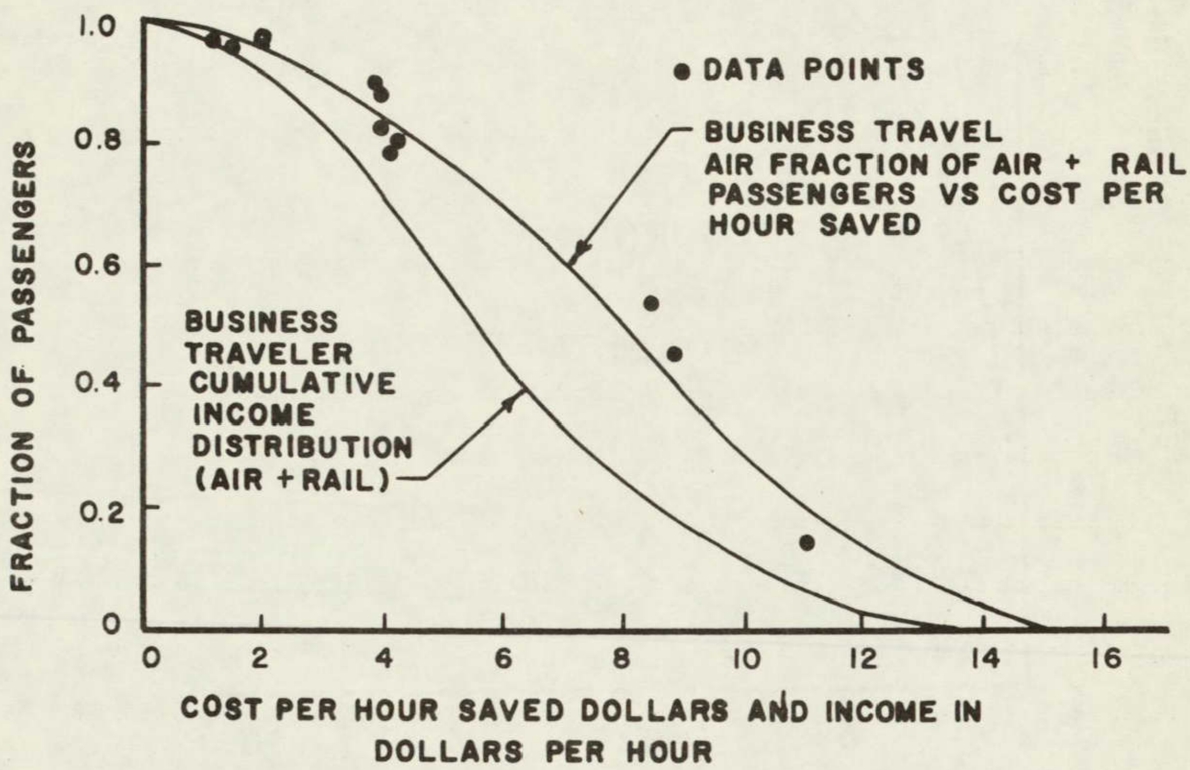


Figure 7.1

7.2.2 Flight Frequency

The frequency of service can have a tremendous influence on air travel. The frequency allocation function is used to generate revenue passenger miles at a specific flight frequency from the potential demand which is at an infinite frequency (See Appendix 7-A). This function is based on the normal probability function and takes into account the variations in competitive transportation trip times. Due to the complexity of the actual scheduling of the flights, it is not considered. It is assumed that the airlines will schedule flights according to the demand fluctuations.

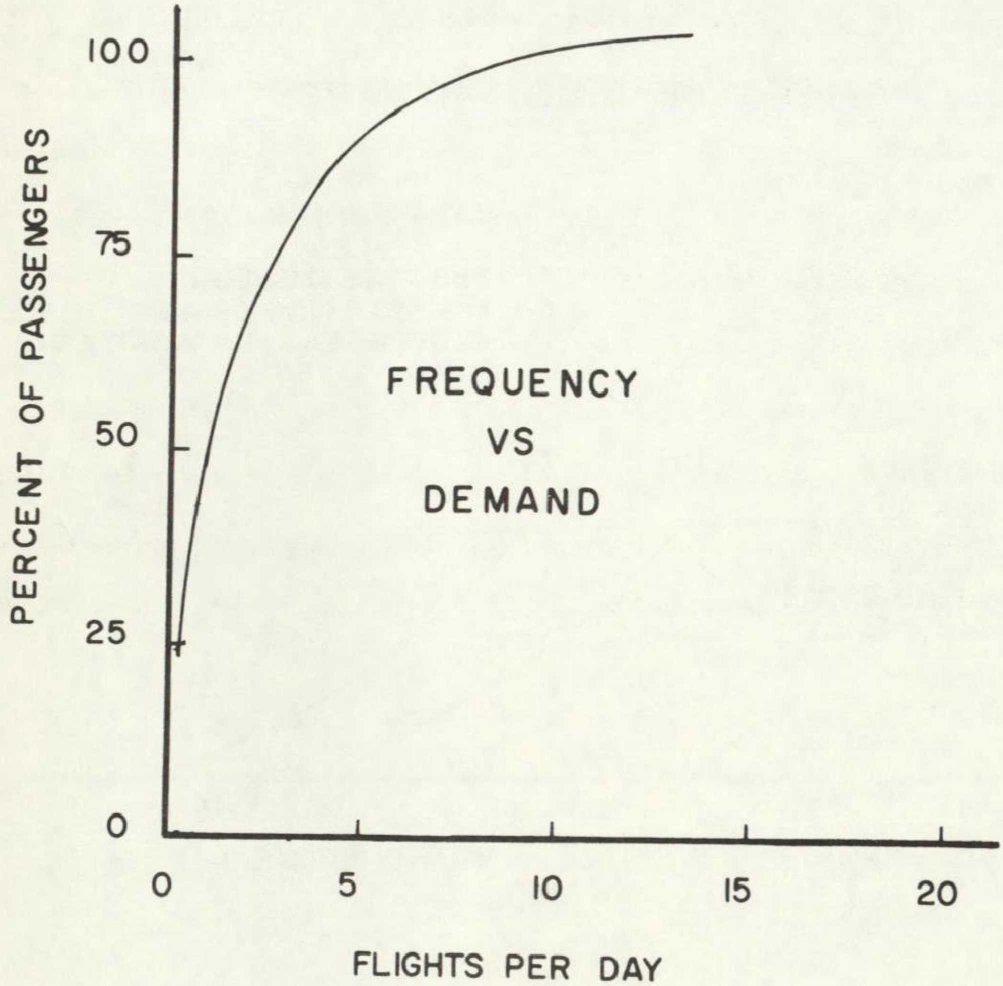


Figure 7.2

7.2.3 Other Effectiveness Parameters

Other effectiveness parameters such as ride comfort, noise and safety are discussed in Appendix 7-A. However, due to the time limitations of the course no projection of these parameters could be made. Therefore they are omitted in the effectiveness function.

7.3 System Cost

The purpose of the cost analysis is the systematic determination of the economic impact of the alternative proposals. Particularly the

economic cost refers to the use of resourses - manpower, raw materials, and the like, necessary to design the system, build it and then operate it for a period of time. Cost analysis is not an end in itself, but serves rather as an input to the general cost-effectiveness analysis.

A typical idealized life cycle of a system is divided into three phases as shown in Figure 7.3. An identical breakdown was utilized for this study. Research and development costs were the investment costs. The operationing costs were estimated over a ten year period from 1975 to 1985. The total system cost was then calculated as a compound amount in 1985. Each group - aircraft, terminal and controls - was responsible for the necessary calculations for their equipment and the equations can be found in their respective models.

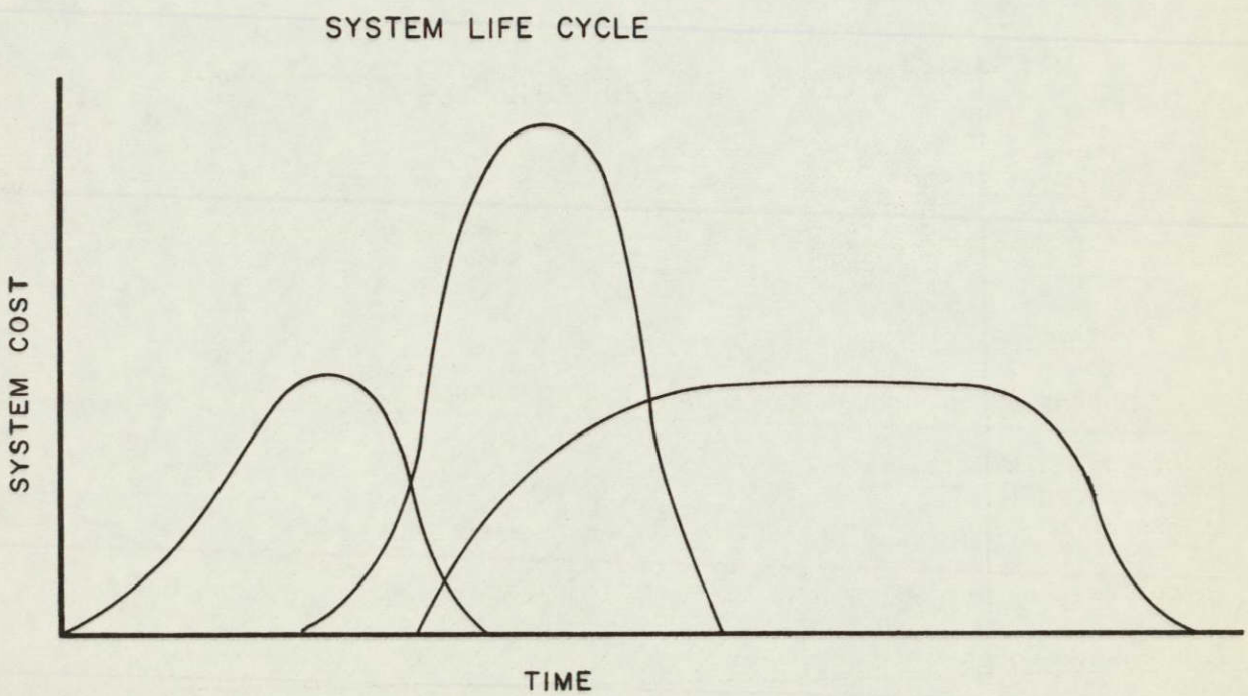


Figure 7.3

7.4 Cost-Effective Analysis

The objective of the cost-effective analysis is to show the relationship between the costs and effectiveness for various alternative solutions. Simply stating these relationships however does not show the optimum or best solution. Usually, either a required effectiveness must be specified and then the cost minimized or that effectiveness, or a required cost must be specified and the effectiveness maximized.

On the other hand, both required cost and effectiveness should not be specified. This over specification can result in asking for alternatives that are either unobtainable (Point A in Figure 7.4) or underdesigned (Point B in the same Figure). An extreme case of over specification is the requirement of maximum effectiveness for the least possible cost. Clearly these requirements are contradictory and can not be met at the same time.

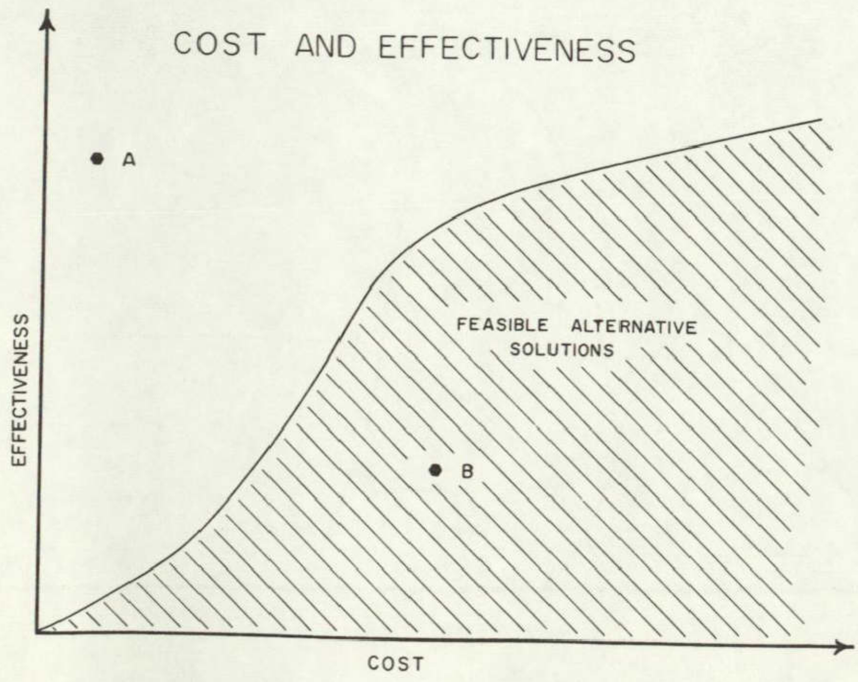


Figure 7.4

The method of obtaining effectiveness used in this study tends to make most systems have approximately the same level of effectiveness, and the study could therefore be judged as a fixed effectiveness model. Further results are explained in the next chapter.

CHAPTER 8

ANALYSIS OF RESULTS AND CONCLUSIONS

8.1 Introduction

Due to the limited time of study, only one computer run involving 189 alternative solutions was made. In this run four variables were investigated. They were:

1. Aircraft Design Range (STOL)
2. Aircraft Cruise Speed (STOL)
3. Aircraft Passenger Capacity (STOL)
4. Air Traffic Control Package

In the simulation,values were assigned to the above variables as input data, resulting in 189 alternative solutions. For each alternative solution, the demand, route structure, aircraft mix, delay, revenue, costs and effectiveness were determined by the models. Also terminals were designed for each city based on the traffic density and type of aircraft utilized at a given city. For each case the system was "operated" for a ten year period. Finally the most cost effective alternative was chosen for "implementation".

Two dependent variables, the total system cost and the system effectiveness were instrumental in making the final design decision. Let us define them carefully here.

Total System Cost is the sum of the direct operating costs and capital recovery for the aircraft, air traffic control system, and terminals for the 1975-1985 period, expanded at six percent interest to the compound amount in 1985. Included are developmental and design costs for new technology and the cost of passengers' time.

System Effectiveness was measured by the total number of passenger miles flown per day.

8.2 Data Acquisition

As an aid in plotting the required data, the "computer team" used a standardized form to record the input and output for each alternative. Only that output which would be used to form the final decision was recorded on these forms. Figure 8.1 shows the format used and the data which was recorded.

DATA RECORDING SHEET

INPUT	Case ____ Stol No. ________ Control Package ________ Design Range ________ Cruise Speed ________ Passenger Capacity ________
OUTPUT	Effectiveness ________ Revenue ________ Cost for Aircraft ____ Cost for Controls ____ Cost for Terminals ____ Total Costs ________

Figure 8.1

From 189 such data sheets, plots of system cost and effectiveness versus design range, cruise speed, passenger capacity, and air traffic control package were made.

As an example Figure 8.2 is a plot of Total System Cost versus passenger capacity for various range aircraft, the air traffic control package and cruise speed being held fixed. In other plots the cruise speed was allowed to vary with some other parameter fixed.

Approximately fifty such plots were used to graphically record the data accumulated.

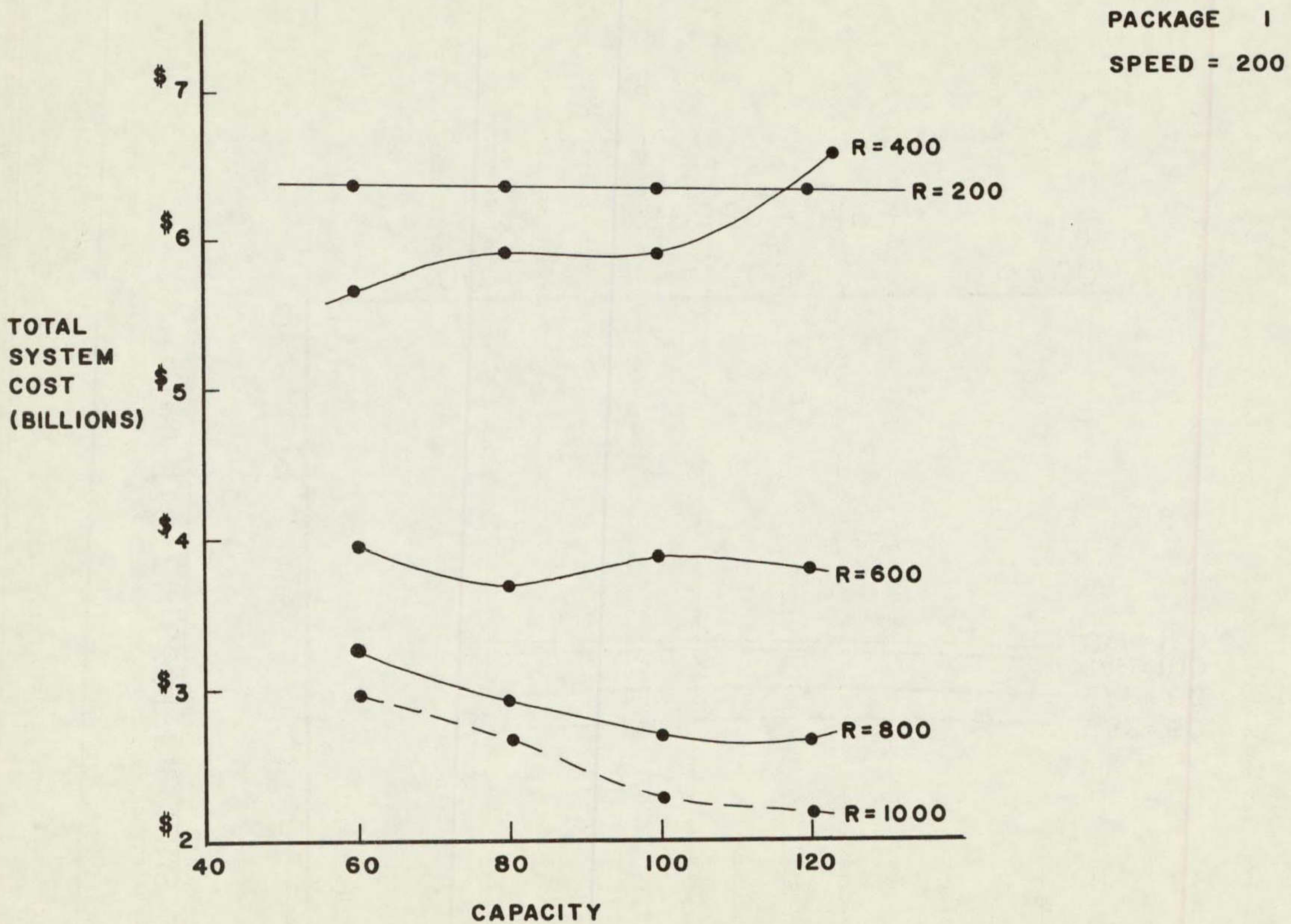
8.3 Analysis of Data

8.3.1 Analysis

Analysis here of the entire data set is prohibited by the large number of graphs required. Those graphs which were most instrumental in making the final decision will be given along with the reasoning involved.

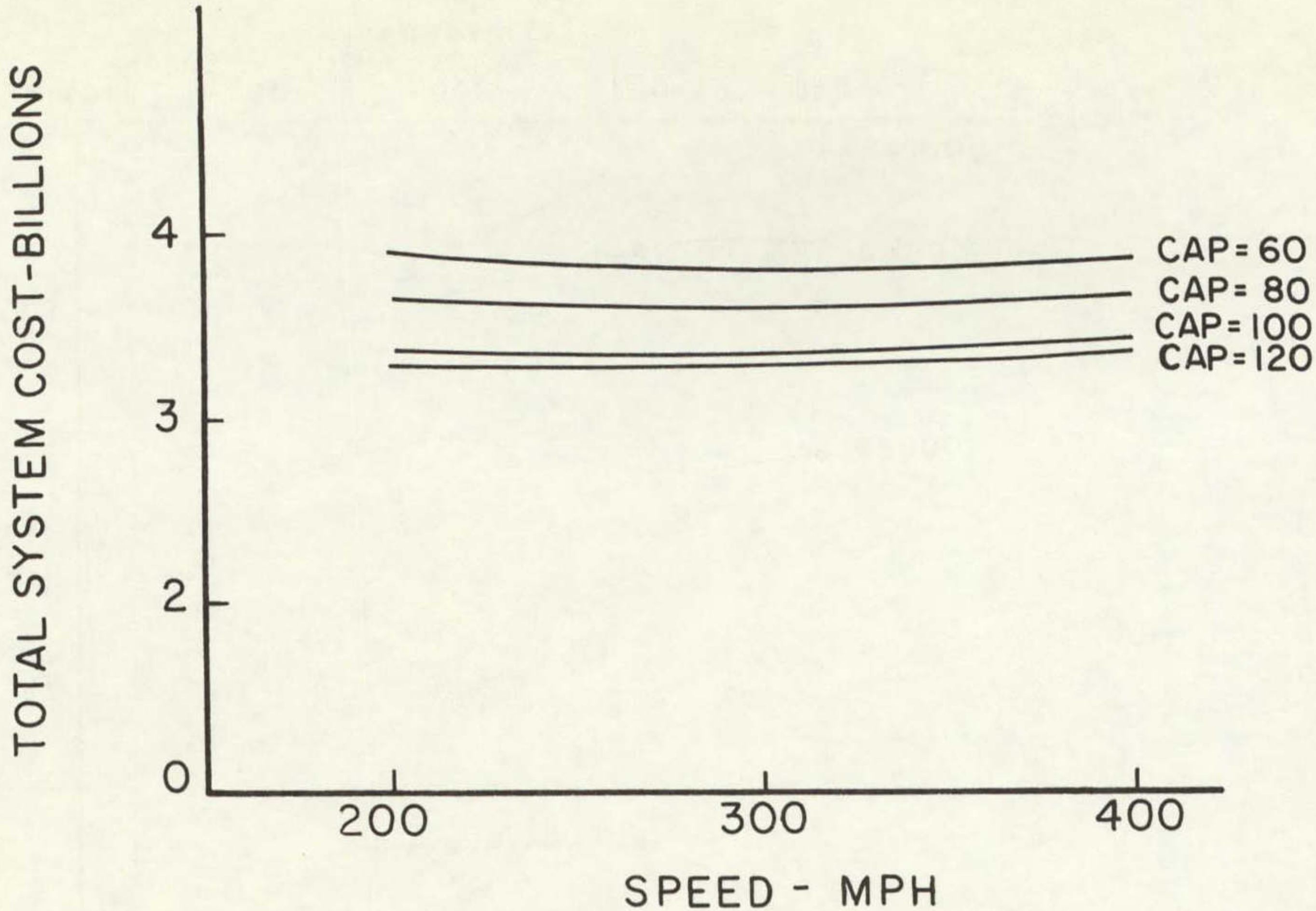
Figure 8.3 indicates that the total system cost was lowest for the larger 120 passenger capacity aircraft. It was also most effective.

Notice in the graph of system effectiveness versus STOL design range, for control package one and 120 passenger capacity (Figure 8.4) that the ordinate varies from 9 to 10 million passenger miles per day. The total variation in effectiveness is therefore only about five percent. Points A and B, representing 600 and 1000 mile design range aircraft respectively are almost equally effective. A plot of total system cost versus aircraft design range (Figure 8.5) indicated that the system incorporating the 600 mile design range aircraft is at a cost roughly twice as much as the one incorporating the 1000 mile design range aircraft (point B).



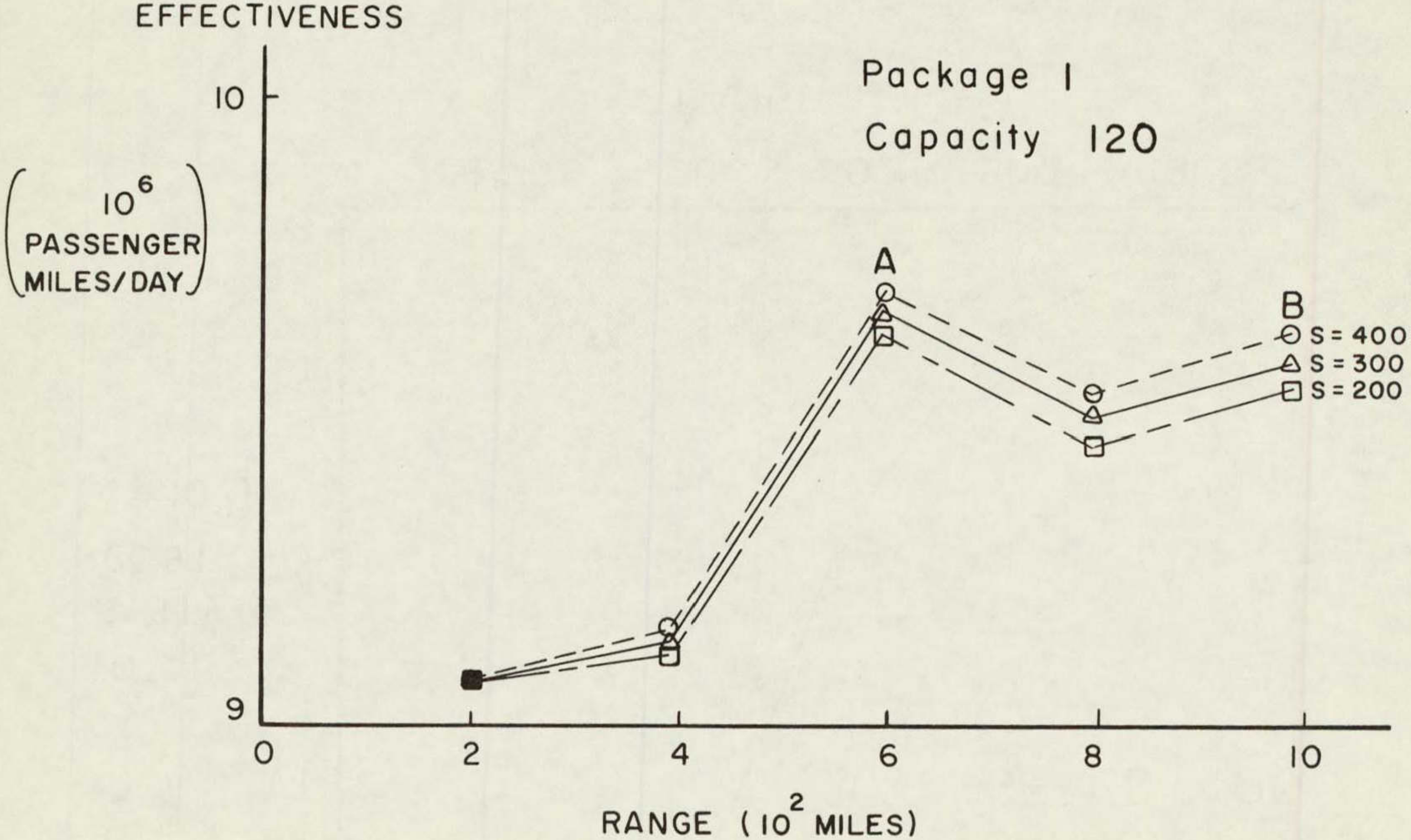
TOTAL SYSTEM COST VERSUS PASSENGER CAPACITY

Figure 8.2



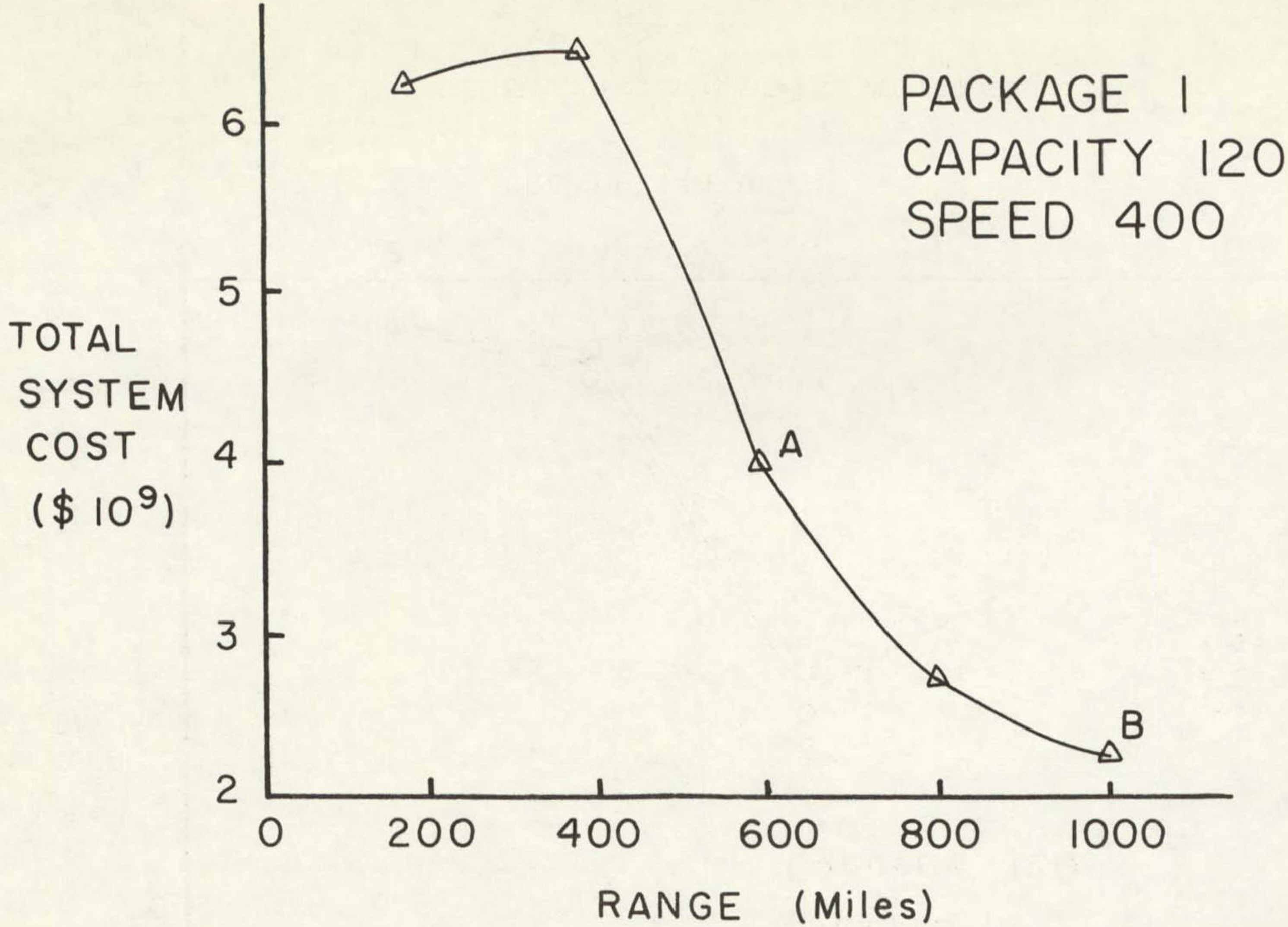
TOTAL SYSTEM COST FOR VARIOUS AIRCRAFT CAPACITIES

Figure 8.3



SYSTEM EFFECTIVENESS VERSUS STOL DESIGN

Figure 8.4

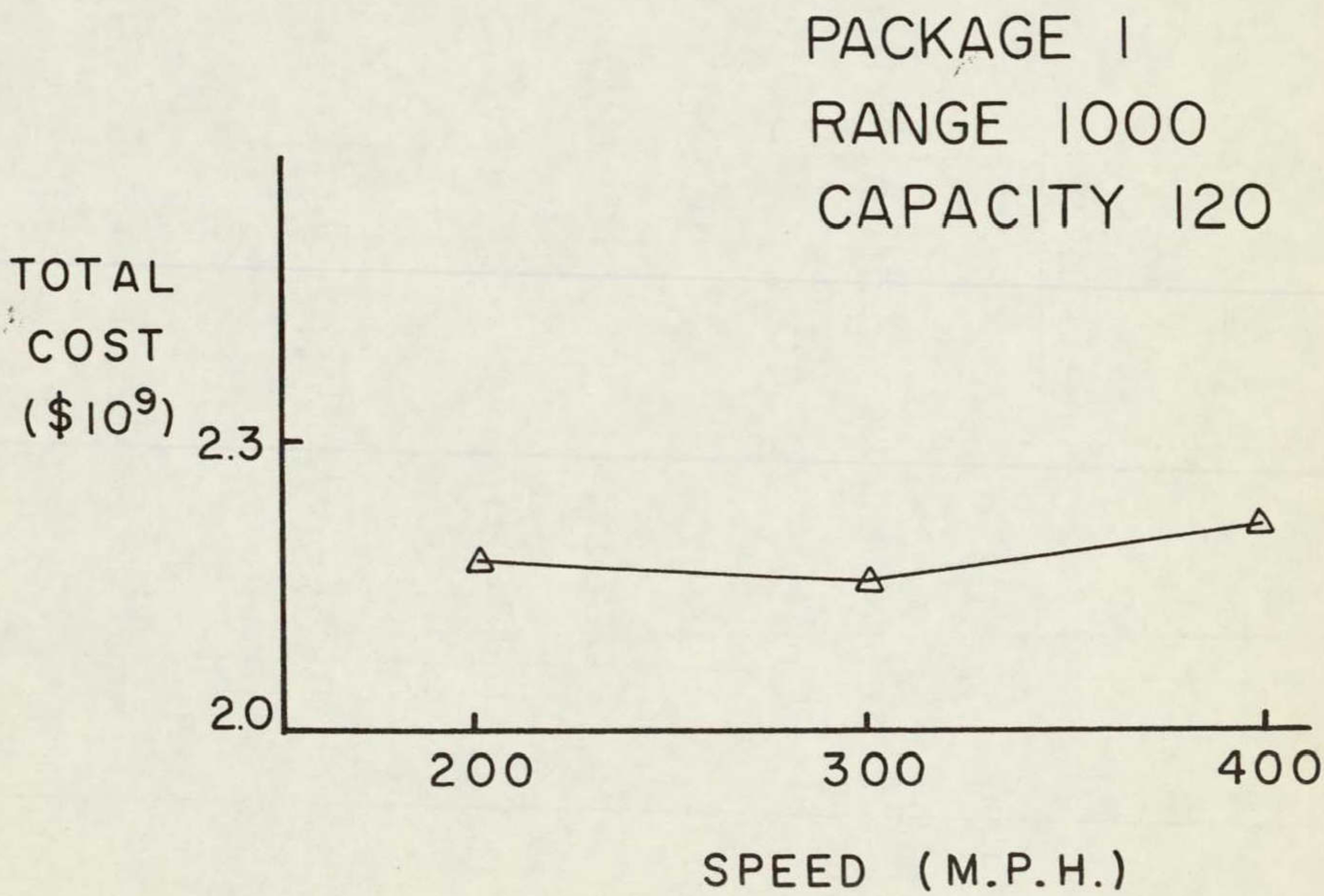


TOTAL SYSTEM COST VERSUS AIRCRAFT DESIGN RANGE

Figure 8.5

A plot of total system cost versus aircraft design range (Figure 8.5) indicated that the system incorporating the 600 mile design range aircraft at a cost roughly twice as much as the one incorporating the 1000 mile design range aircraft (point B).

Referring again to Figure 8.4, notice that the total variance in system <u>effectiveness</u> with aircraft design speed is only one and one half percent. Figure 8.6 indicates that the variance in <u>total system cost</u> with aircraft design speed is also minimal for the 1000 mile design range aircraft.



MINIMAL VARIANCE IN TOTAL SYSTEM COST

Figure 8.6

Aircraft

CTOL- L-1011

STOL -Four Engine Turbo Prop — 25500 H.P.

Cruise Speed	400 M.P.H.
Range	1000 Miles
Capacity	120
Length	98.5 ft.
Span	92 ft.
Gross Weight	105,000 lbs.

THE MOST COST EFFECTIVE AIRCRAFT COMBINATION DETERMINED

Figure 8.7

Because of the small variation in system cost and effectiveness with aircraft cruise speed, the faster 400 mph CTOL aircraft was arbitrarily chosen for the system.

All of the plots were originally made to the same scale on translucent graph paper so that by comparing various plots on a tracing table, it was determined that Package One, the present day Air Traffic Control System was no less effective than the other two considered and was less costly.

8.3.2 Results

By the preceeding analysis the following system was determined to be the most cost effective.

The aircraft combination (Figure 8.7) includes the Lockheed L-1011 Jumbo Jet which represented the CTOL aircraft in the system simulation. The STOL is a four engine turboprop with a total of 25,500 H.P. It requires a 1000 ft runway, has a cruise speed of 400 mph and 1000 mile design range.

The air traffic control system is the conventional instrument landing system. Terminals are designed for various cities as required by the aircraft mix. Some cities have only a CTOL port, others a STOL port, and some a CTOL port with an additional STOL runway. (Fig. 8.8) This fully describes the system.

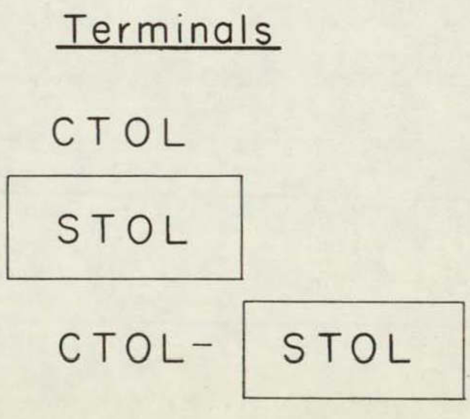


Figure 8.8

8.3.3 A Closer Look at the Results

Some of the indicated results are rather unexpected. It is known, for instance, that the present air traffic control system is inadequate even today. It must be remembered that these results are based on a single computer run, in fact, the first run ever made with all the models functioning together.

In the system using short range STOL aircraft the terminal costs greatly exceeded the aircraft costs, while aircraft costs were slightly greater than terminal costs where long range STOL were in the system. (Figures 8.9 and 8.10).

This can be explained by looking at the effect of Demand on System Cost (Fig. 8.11) when the total number of operations is low, the fixed costs of the terminals are predominate. This effect was amplified when short range STOL were in the system, requiring many more of the expensive CTOL terminals than the long range STOL system requires. The effect was further exagerated by the fact that the CTOL model was written for the moderate to high demand of larger cities. Its fixed costs therefore include a tower, hangers, fire fighting equipment and the like rather than the runway and wind sock required by a very low number of daily operations. The STOL port in contrast has a relatively low fixed cost.

The air traffic control system design might also have changed had the demand been higher. The plot of delay versus number of operations given in Fig. 8.12 shows very little difference in delay for the three control packages when the number of operations is low. There is, however, a considerable difference in delay for the three packages when the number of operations is high. The air traffic control design would most likely have been different had congestion been generated.

RELATIVE COSTS FOR "POOR CASE"

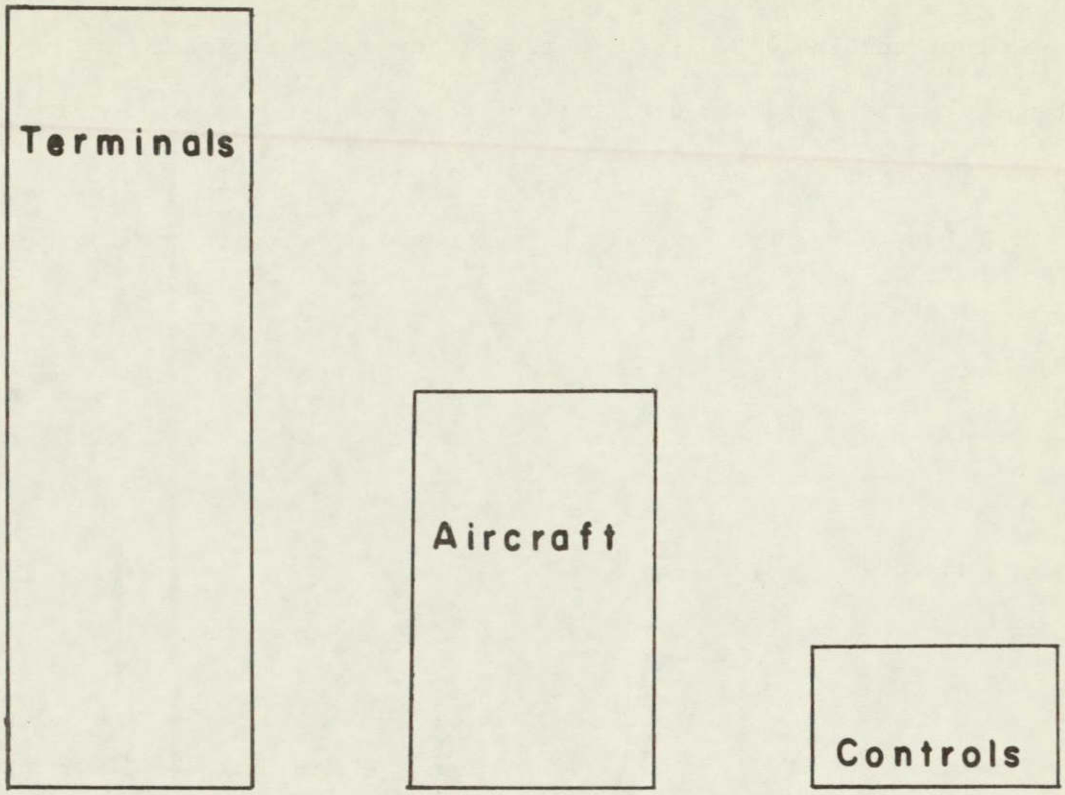


Figure 8.9

RELATIVE COSTS FOR "BEST CASE"

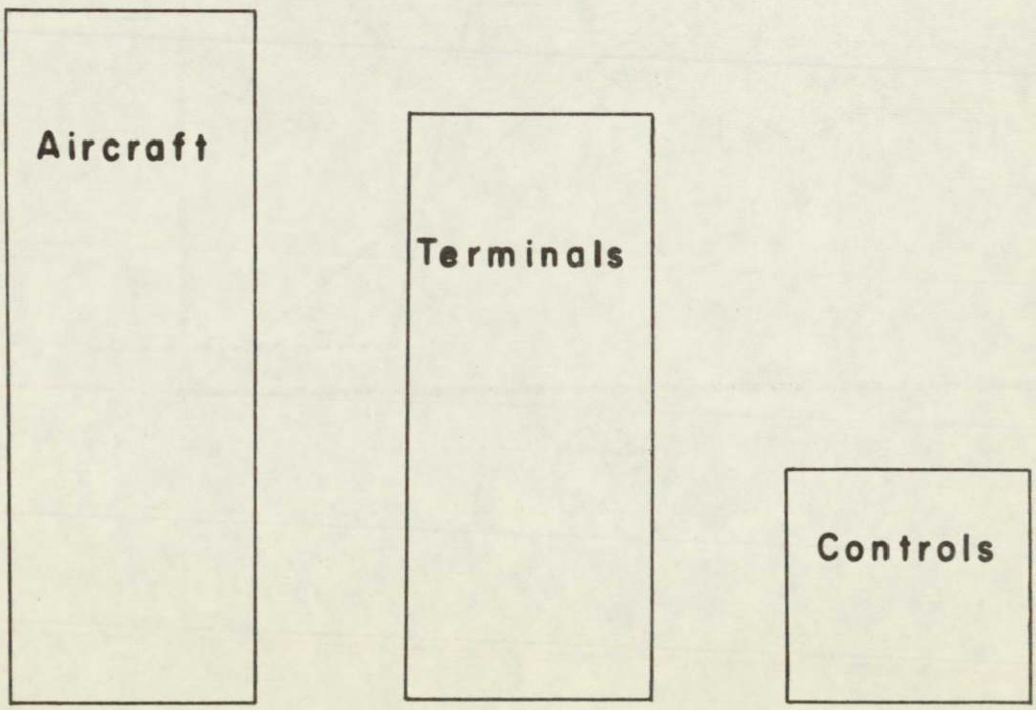
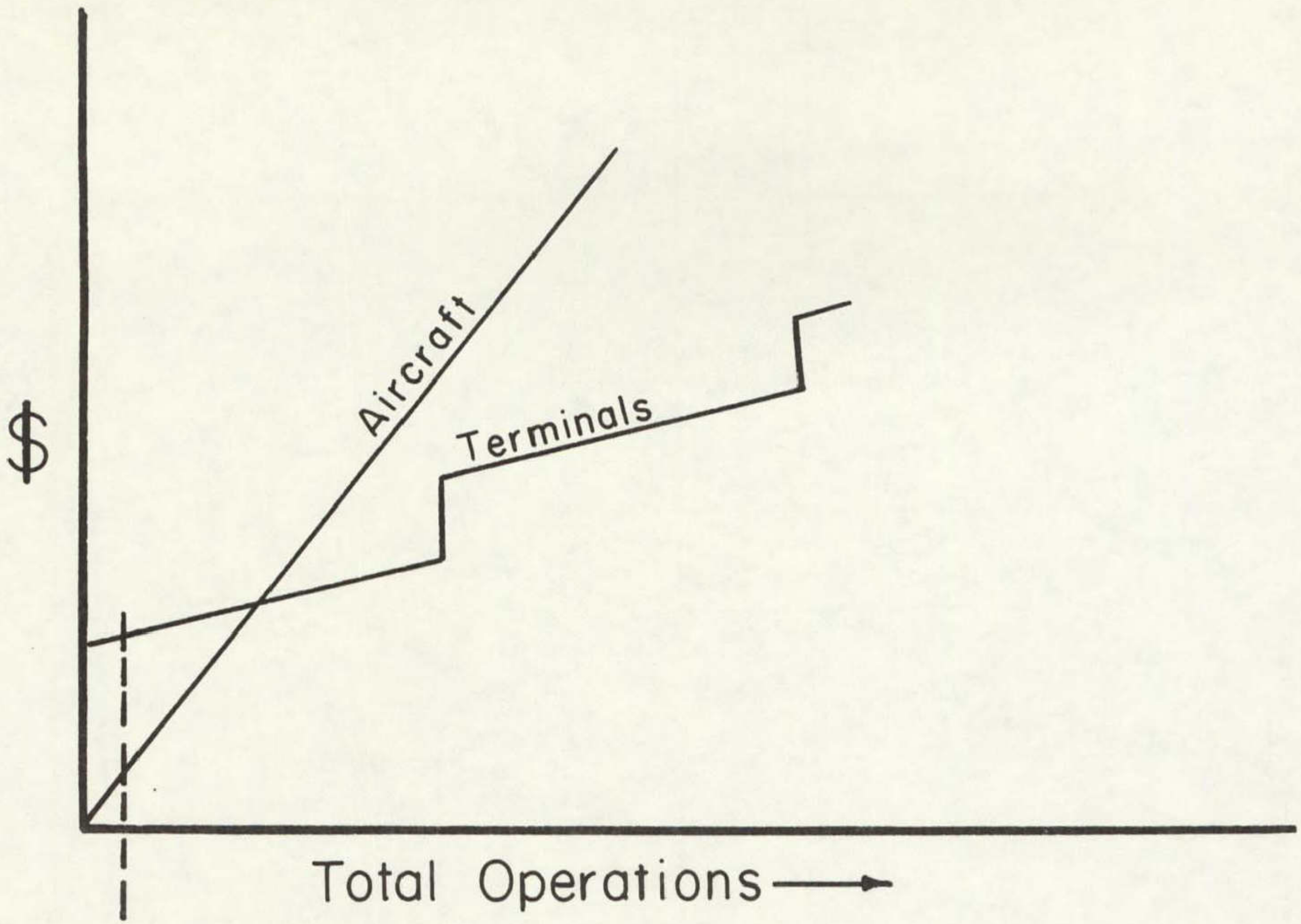
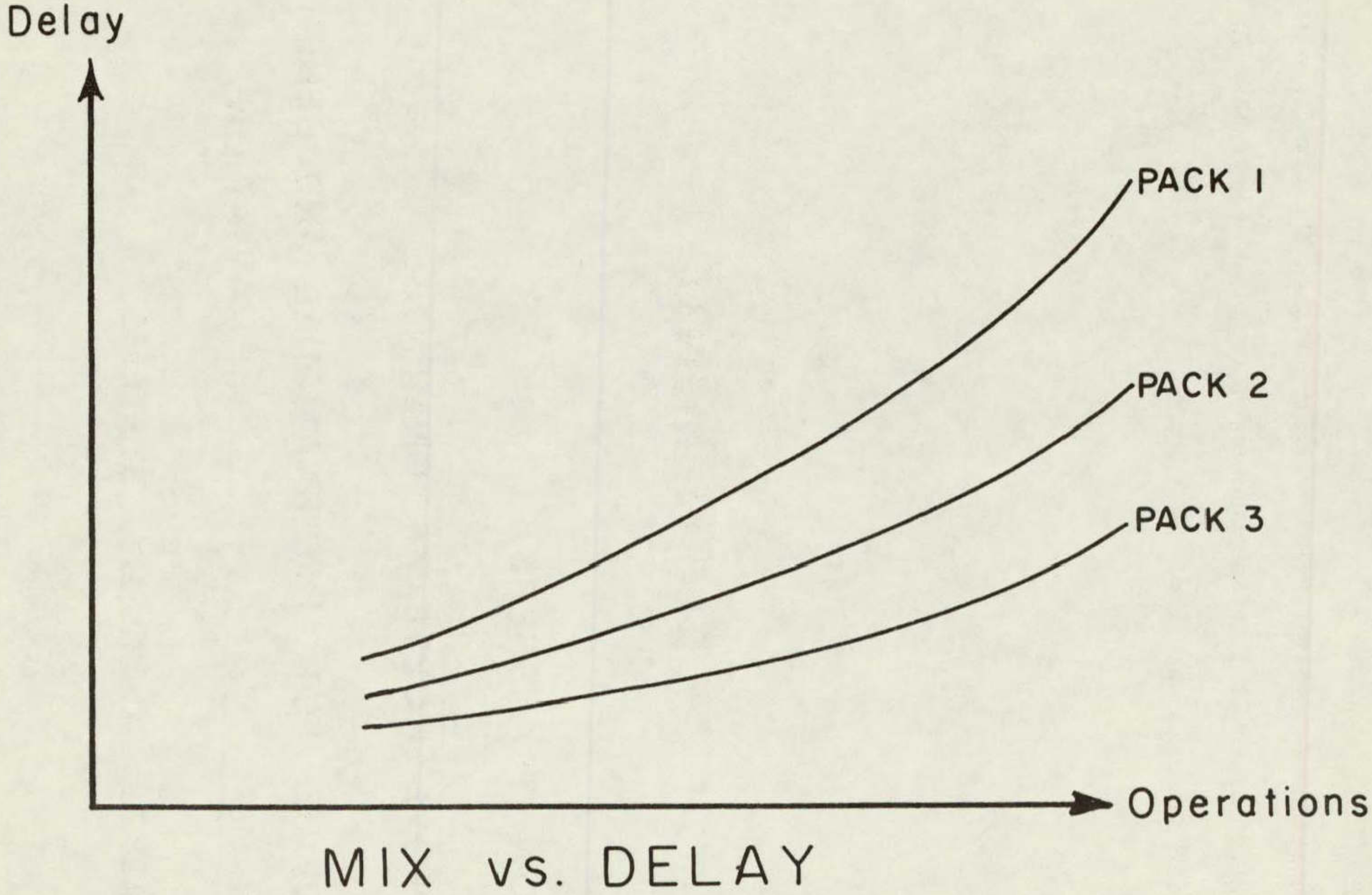


Figure 8.10



THE EFFECT OF DEMAND ON SYSTEM COST

Figure 8.11



DELAY VERSUS NUMBER OF OPERATIONS

Figure 8.12

Most of the questionable results can therefore be traced to low traffic density in the first simulation.

8.3.4 Refinements

Consideration of the difficulties encountered in the first run led to determination of several refinements which could have been made in the simulation had time permitted. (Fig. 8.13)

REFINEMENTS

- ALLOW TRANSFERS
- IMPROVE ROUTE ASSIGNMENTS
- PROVIDE FOR INTERNATIONAL AND GENERAL AVIATION
- ANALYZE CURRENT SYSTEMS

Figure 8.13

The first refinements to be made would be to allow passenger transfers and to assign aircraft to routes by cost-effective analysis rather than by range. These changes would increase traffic and make the simulation more realistic. Provisions for international flights and general aviation in the models would also provide additional traffic for the system. Finally, the DC-9 flown as a STOL aircraft in the system compared well with the design STOL. It would be helpful to simulate a total CTOL system to provide a comparison for the STOL'S advantages and disadvantages.

The design STOL is the largest, fastest, longest range STOL considered. It would be advisable therefore to run still larger, a faster, and longer range STOL in a second simulation in order to find the truly optimum system.

APPENDIX 1-A

SEMINARS ON INTERURBAN TRANSPORTATION

January 21, 1969

Captain Thomas Oakes, Director of Flight Operations Capability Project, Eastern Air Lines

"Short Range Air Transportation - Next Generation Vehicles and Control"

January 23, 1969

Professor William W. Seifert, Director, Project TRANSPORT, Massachusetts Institute of Technology

"Systems Aspects of High Speed Ground Transportation"

January 28, 1969

Alan M. Voorhees, Alan M. Voorhees and Associates

"Public Reaction to Transportation Improvements"

February 6, 1969

C. W. Randall, Sales Staff Supervisor, Southern Bell Telephone

"Can Communication Substitute for Transportation?"

February 11, 1969

Robert Gladstone, Robert Gladstone and Associates

"Land Use Considerations in Urban Air Terminal Design"

February 18, 1969

Dr. Robert Simpson, Director of Flight Transportation Laboratory, Department of Aeronautics and Astronautics, Massachusetts Institute of Technology

"V/STOL Aircraft as the Interurban Transportation Mode"

February 20, 1969

Dr. Morton I. Weinberg, Head of Transportation Systems Section, Cornell Aeronautical Laboratory, Inc.

"Intercity Transportation Modes of the 1980's"

APPENDIX 1-B

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1, 2 First and second quarters only respectively

APPENDIX 3-A

This appendix details the study of variation in travel demand and the methodology used in forcasting that demand. Specific information pertinent to a more complete understanding of these subjects is presented here. As such, the relevant portions of Chapter 3 should be read in conjunction with the material presented here.

3-A-1 Variations in Demand

It is obvious that air travel demand does not remain constant with time. Seasonal, daily, and hourly peaks are almost always experienced. The design of the terminal must be based on a knowledge of these peak periods so that a determination of design volume and load factors can be made. These variations are discussed below.

3-A-1.1 Seasonal Peaks

At this time, statistics for the calendar year 1967 are the most recent available. Figure 3-A-1, Seasonal Variation in Demand, plots per cent of total revenue passenger miles against the month of the year. The results are also tabulated on table 3-A-1. It is assumed here that the use of schedule timing does not affect the month in which the user flies. For shorter periods of analysis (days, hours) this assumption is questionable.

As shown in Figure 3-A-1, the seasonal peak occurs during the summer months, where in the month of August, approximately 10.5 percent of the annual travel occurs. This peak reflects an increase in vacation travel during December, caused by the increased travel demand for the Christmas holidays.

3-A-1.2 Daily Peaks

Data on weekly air carrier operations has been extremely difficult to obtain. Further investigation is necessary in this area. However, studies

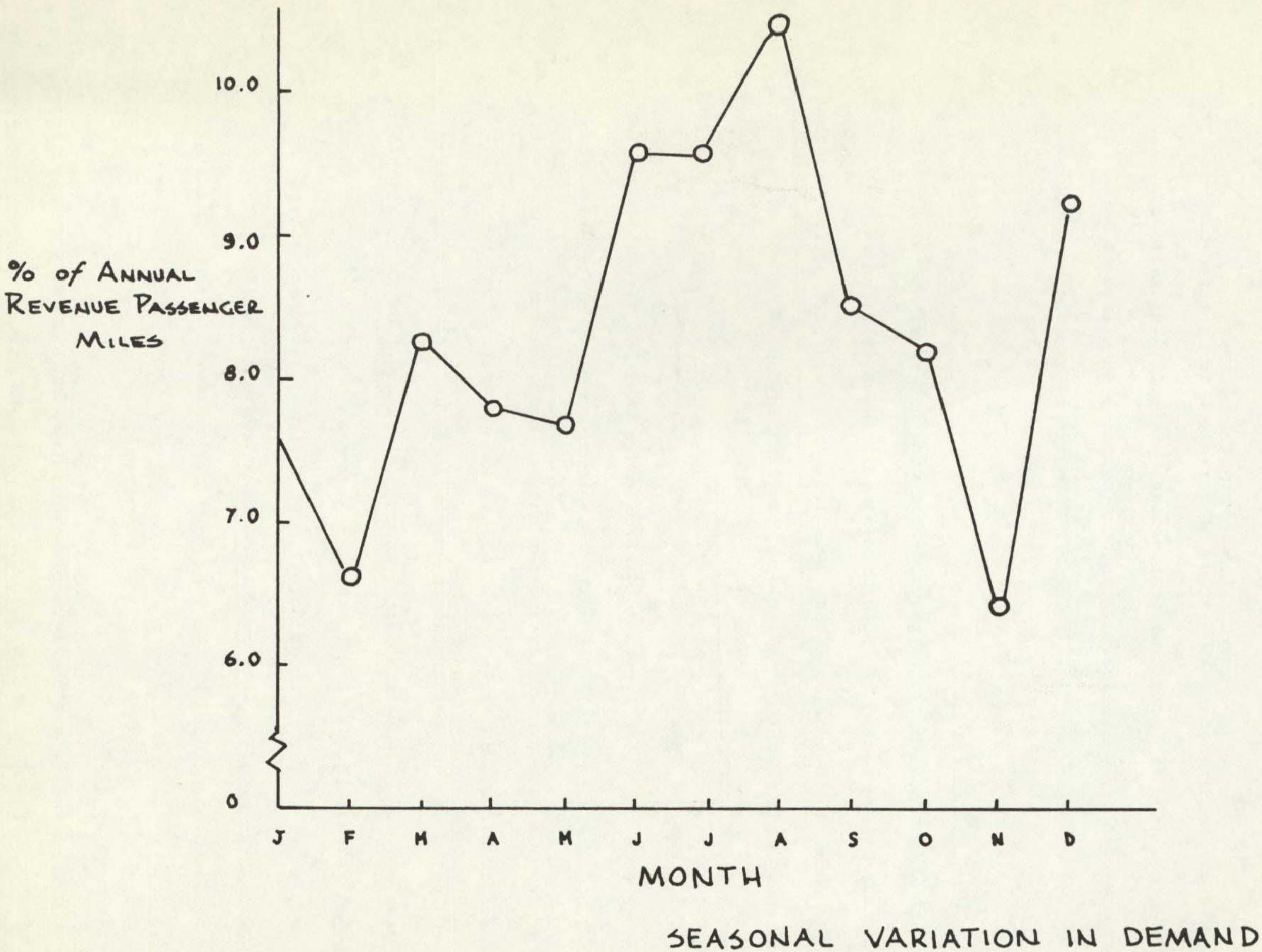

% of ANNUAL
REVENUE PASSENGER
MILES
10.0
9.0
8.0
7.0
6.0
0
J
F
M
A
M
J
J
A
S
O
N
D
MONTH
SEASONAL VARIATION IN DEMAND

Figure 3-A-1

TABLE 3-A-1

Seasonal Variation in Demand

Month	R.P.M. (millions)	% Total
J	5300	7.6
F	4600	6.6
M	5800	8.3
A	5500	7.8
M	5400	7.7
J	6700	9.6
J	6750	9.6
A	7323	10.5
S	5950	8.5
O	5750	8.2
N	4450	6.4
D	6450	9.2
	69973	

Key: R.P.M. = Revenue Passenger Miles

Source: Civil Aeronautics Board, Handbook of Airline Statistics

previously undertaken show the demand for Friday and Monday to be higher than for the rest of the week, reflecting the dependence of weekly travel on the business trip.

3-A-1.3 Hourly Peaks

As in the automobile travel demand, air travel also experiences two daily peaks, one during the early morning and the other in late afternoon. This is shown in Figure 3-A-2, Hourly Variation in Demand. The hourly variation during the peak day does not show definite peaks as does the average day, but remains fairly constant throughout the day, except for the early morning. Again this points out the fact that peak hour passenger volumes are influenced a very great deal by non-business travel.

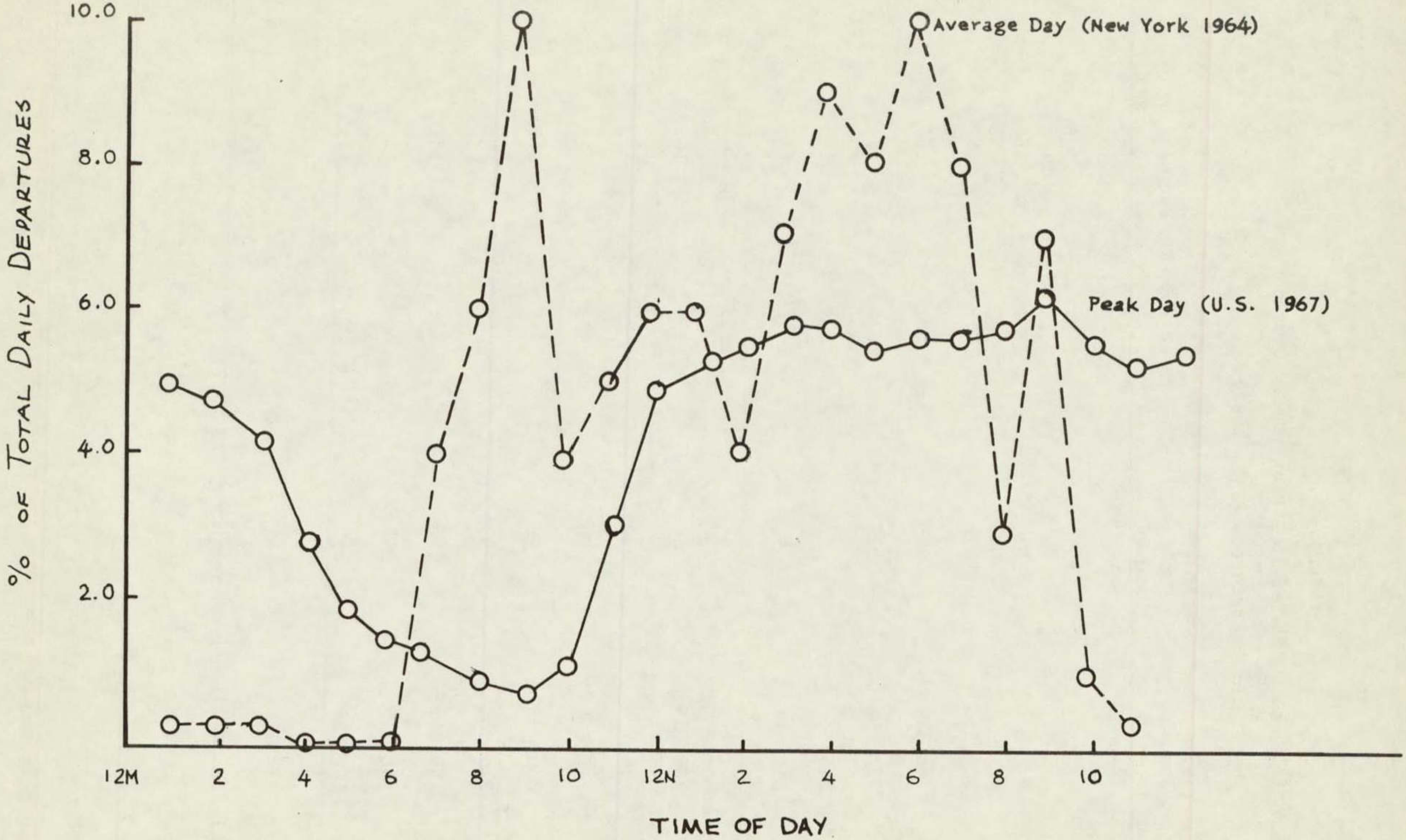
3-A-1.4 Peak Day and Busy Hour as Related to Average Daily Traffic

The ratio of the peak day and the average daily traffic is of great relevance in determining the design volume of the terminal and aircraft. Of equal importance is the ratio of busy hour to the average daily volumes. Both of these areas are investigated and discussed below.

3-A-1.5 Ratio of Peak Day to Average Daily Traffic

The peak day is that 24 hour period beginning at midnight in which the airport handles the highest traffic volume of the year. Average daily traffic is simply the annual volume divided by 365 days. Peak day departures as a per cent of average daily departure were plotted for major air centers for fiscal year 1967. The results are tabulated in Table 3-A-2 and plotted in Figure 3-A-3.

The average value of the peak day departures as a per cent of average daily traffic was 169. In 1964, 1965 and 1966 these values were 163, 171 and 178 respectively. Therefore, it cannot be said with any confidence at this point what the annual trend of the peak day/average daily traffic ratio is.



HOURLY VARIATION IN DEMAND

SOURCES: Federal Aviation Agency, Port of New York Authority

Figure 3-A-2

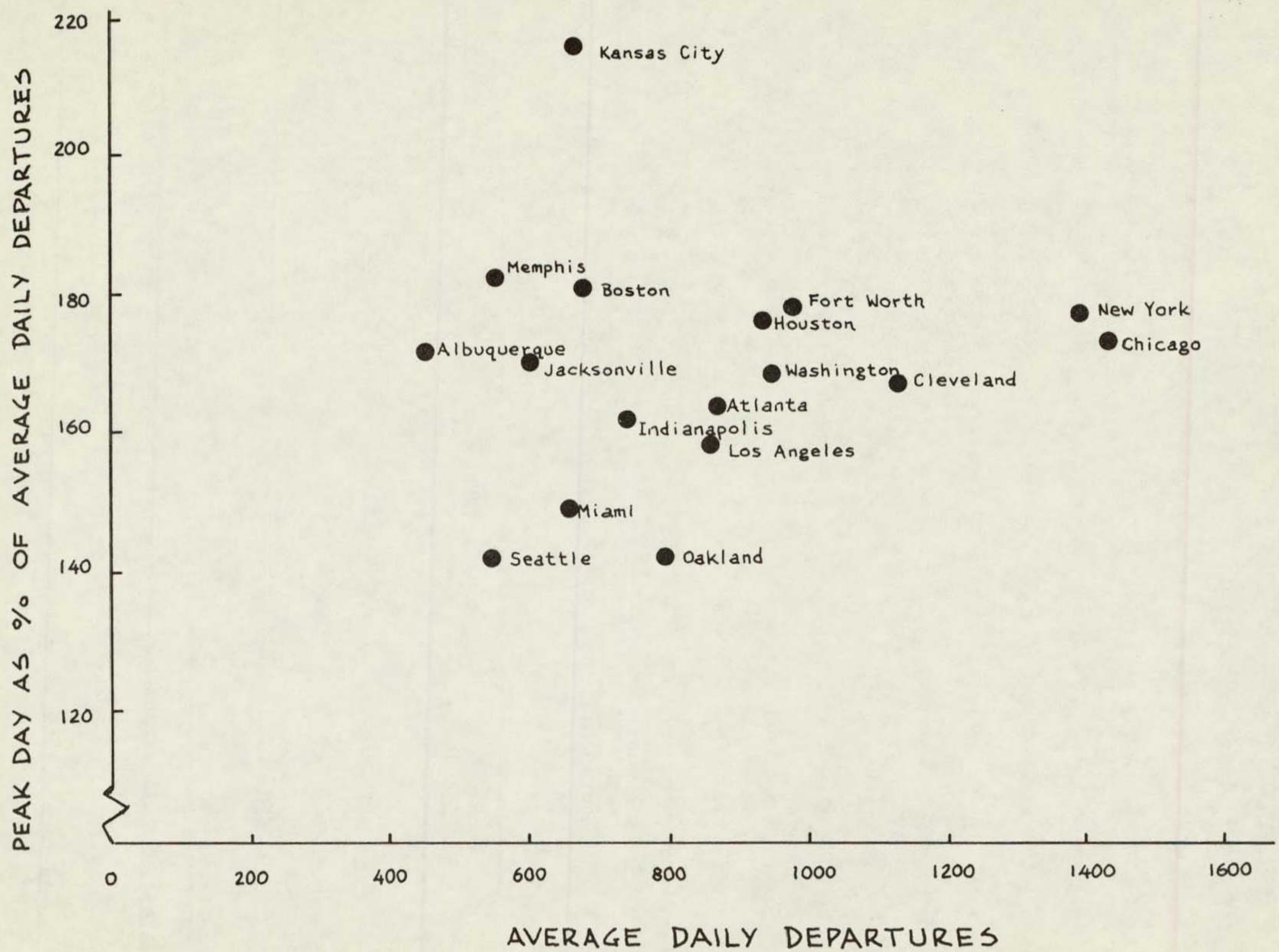
TABLE 3-A-2

Peak Day Demand Related to Average Daily Demand

I.F.R. Departures (F.Y. 1967)

Center	Annual	Daily Average	Peak Day	Per Cent of Daily Average
Chicago	521,481	1429	2455	172
New York	506,655	1388	2447	176
Cleveland	410,940	1126	1871	166
Fort Worth	354,663	972	1718	177
Washington	346,334	949	1591	168
Huston	338,994	929	1628	175
Atlanta	314,660	862	1409	163
Los Angeles	311,891	654	1339	157
Oakland	287,129	787	1107	141
Indianapolis	268,036	734	1179	161
Boston	243,971	668	1205	180
Mimai	240,846	660	977	148
Kansas City	236,789	649	1395	215
Jacksonville	215,564	593	1005	169
Memphis	199,345	546	986	181
Seattle	198,215	543	768	141
Albquerque	160,739	330	535	171

Source: F.A.A. I.F.R. Air Traffic Activity (F.Y. 1967)



PEAK DAY DEMAND RELATED TO AVG DAILY DEMAND

Figure 3-A-3

3-A-1.6 Ratio of Busy Hour to Average Daily Traffic

Busy hour data for the entire United States is not compiled by the F.A.A. or C.A.B. and is not readily available otherwise. However the F.A.A. Air Traffic Division, Airport Activity Data sheets (RIS-AR-7230-16) were obtained, which list the busy hour operations for the southern region. Unfortunately, the limited data reduced the reliability of the busy hour study, since it included only a few major airports in the south. The data used, however, is compiled in Table 3-A-3. Busy hour Demand Related to Average Daily Demand.

The busy hour demand as a per cent of average daily demand varied from a high of 21.3 per cent for San Juan to a low of 4.0 per cent for Jacksonville. Obviously more data on airports outside the southern region is needed. The results of the investigation are inconclusive.

TABLE 3-A-3 Busy Hour Demand Related to Average Daily Demand (F.Y. 1967)

Center	Annual	Daily Average	Hour	Per Cent of Daily Average
Atlanta	324,660	862	49	4.5
Miami	240,846	660	53	8.0
Jacksonville	216,564	593	24	4.0
Memphis	119,345	546	54	9.9
San Juan	53,417	146	31	21.3

3-A-2 Details of the Demand Model

The gravity model suggested by M.I.T. states that the traffic demand between two population centers is proportional to the product of their populations and inversely proportional to some power of the distance between them:

$$T_{ij} \propto \frac{P_i P_j}{D_{ij}^{\,a}} \qquad (1)$$

where: T_{ij} = traffic between the i^{th} origin and the j^{th} destination.

P_i = population of i.

P_j = population of j.

D_{ij} = distance between i and j.

a = constant associated with air travel.

If a proportionality constant (K) is inserted, the resulting relationship can then be expressed as an equation:

$$T_{ij} = K \frac{P_i P_j}{D_{ij}^{a}} \tag{2}$$

As the distance between the pair of cities approaches zero, the travel increases without bound. Since this is not characteristic of air transportation, a modification is made which, for short distances, reduces the travel demand until a meeting with the gravity model curve occurs.

$$T_{ij} = K \frac{P_i P_j}{D_{ij}^{a}} \left(1 - e^{-(dD_{ij})^2}\right) \tag{3}$$

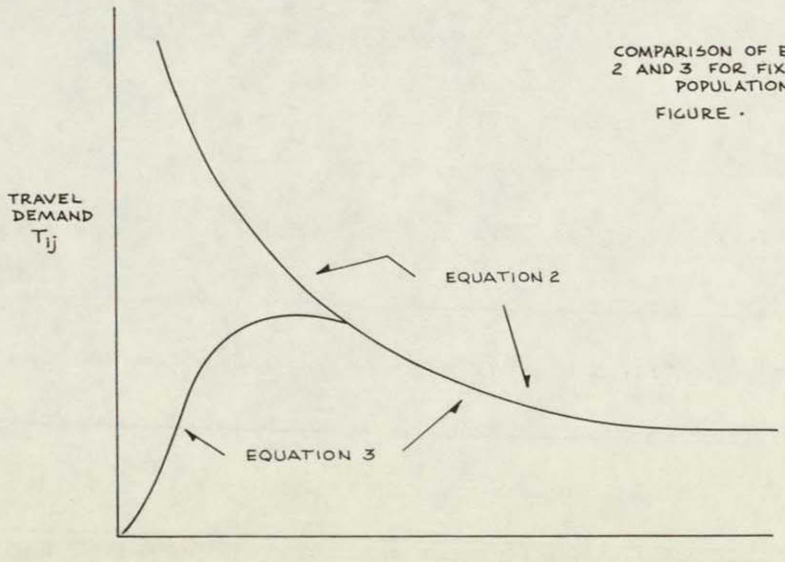


Figure 3-A-4

Using the above equation, with a constant value of K, growth in travel demand is completely dependent on growth in population of the various areas. Since population growth has been much slower than the growth of transportation demand, it must be concluded that K is not constant, but a function of time, K(t). A suggested modification in Equation (3) to include an annual percentage change in air travel demand is:

$$T_{ij}(n) = K \frac{P_i(n)\, P_j(n)}{D_{ij}^{\ a}} \left[1 - e^{-(bD_{ij})^2} \right] \left[1 + \frac{t_{ij}}{100} - \frac{p_i}{100} - \frac{p_j}{100} \right]^n \qquad (4)$$

where: $T_{ij}(n)$ = travel demand, n years after vase year

$P_i(n)$ = population of city i, n years after base year

$P_j(n)$ = population of city j, n years after base year

$p_i(n)$ = annual percentage change in population of city i

$p_j(n)$ = annual percentage change in population of city j

t_{ij} = annual percentage change in air travel demand

D_{ij} = distance from city i to city j

a, b = empirically derived constants

A complete derivation of this can be found in the Lockheed-Georgia Company report [3].

Two final adjustment factors were also considered in adapting the final model. Cities of the same population may not generate the same volume of traffic because of differences in income factor (I_i) to adjust the traffic volume. A second factor to consider is the attractiveness of a city to

travelers and businessmen. Because of the complexity of measuring this factor, it was omitted from the final model.

3-A-3 Final Model of Demand

A computer program was developed that will calculate T_{ij} for 144 Urbanized areas in the United States and described by the U.S. Bureau of the Census [4]. Areas were omitted if sufficient data was not available to allow forecasting population into the future. Predictions were made for the years 1970, 1980, 1990, and 2000, based on Equation (5).

$$T_{ij}(n) = K \frac{P_i(n)\, P_j(n)}{D_{ij}^{\,a}} \left[1 - e^{-(bD_{ij})^2} \right] \left[1 + \frac{t_{ij}}{100} - \frac{P_i}{100} - \frac{P_i}{100} \right]^n \cdot I_i \qquad (5)$$

The constants were reevaluated after the program had sucessfully completed the initial run and a comparison of results could be made with other predictions.

3-A-4 Reduction of the Network

A network of 144 cities can be connected by over 10,000 direct links. Due to practical limitations of time and computer facilities it was necessary to reduce the study area to a smaller network with fewer cities and their connecting links. Since it would be hard to find one area in the nation which would be considered typical or represenative of the entire United States, a reduced network was constructed without reference to any specific area or region of the nation. In the determination of the reduced network, two characteristics seem to have prime importance. The geographic distribution of the cities of the reduced area should be similar to that of the larger area and the trip generating potential of the cities of a given size should not be affected

by the reduction. With these considerations in mind, a sample area was created.

3-A-4.1 City Size and Geographic Distribution

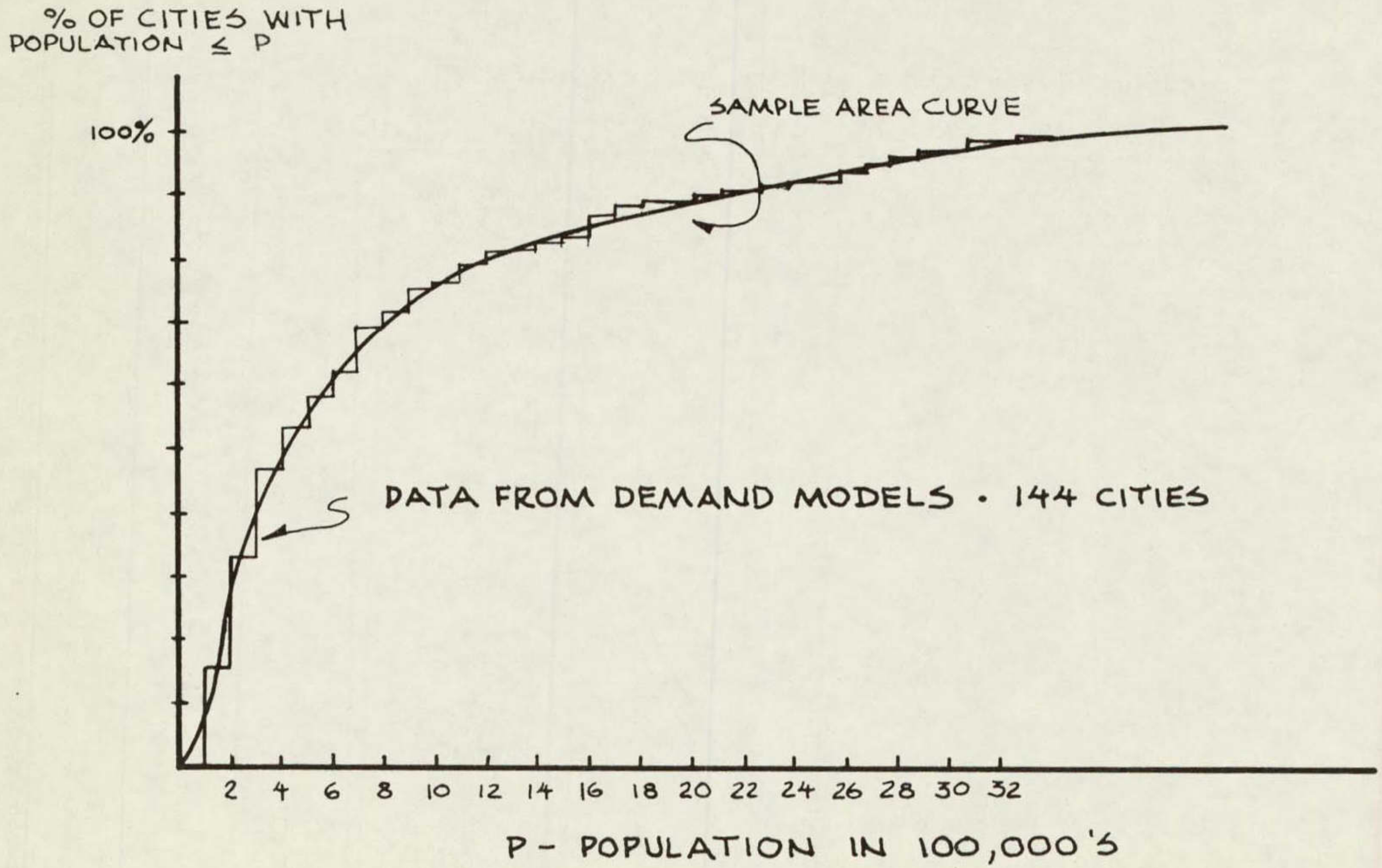
The choice of a typical area should not bias the results of the study by having too many small cities for the total number included, likewise it should not be dominated by too many large ones. The population of each city in the sample area is fixed so that the sample area will have approximately the same probability distribution function as that of the 144 urbanized areas originally considered. Figure 3-A-5 compares the two distributions.

Construction of a typical network involved specification of distances between cities as well as the demand. To accomplish this a summary of the number of connecting links for various length trips was taken from the data available on the 144 urbanized areas. For the purposes of this study distances of over 2000 miles were not considered. All other links were summarized in a cumulative function.

A trial-and-error method was then used to construct an arrangement of eleven cities which would have a similar cumulative distribution. Figure 3-A-6 indicates the two distributions and Figure 3-A-7 is a scale drawing of the area finally selected for the study. Assignment of populations to the locations in this arrangement was a similar trial-and-error process, however, no attempt was made to construct a cumulative plot of percent of total trips versus distance of trip.

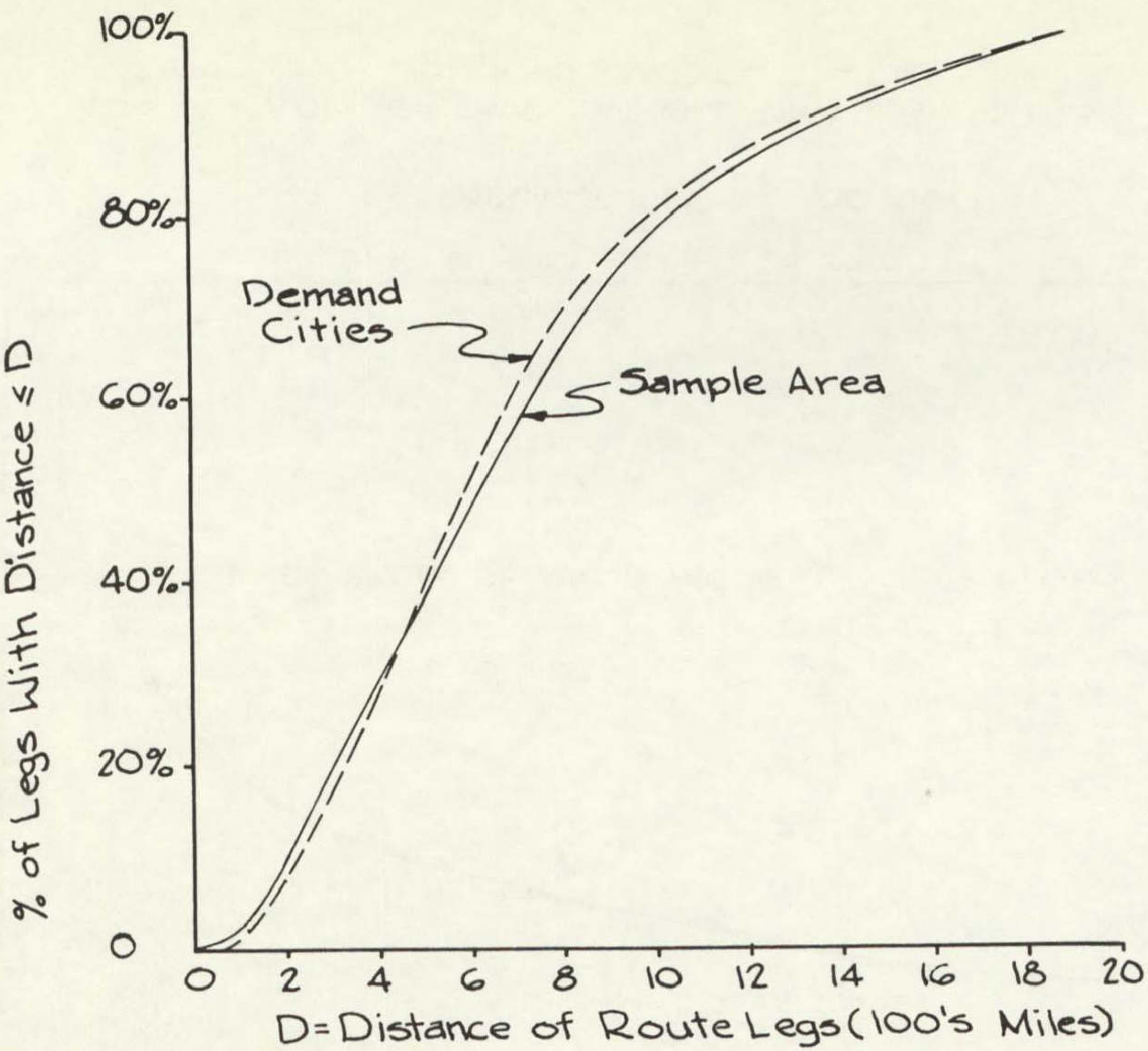
3-A-4.2 Trip Generation Potential of Cities

Since the reduction in the number of cities under consideration reduces the number of possible destinations for a given city, total trip producing potential for that city is reduced unless trips external to the sample area are considered. This was accomplished by first predetermining the trip producing potential of a city based on its projected population and then subtracting the internal trips for this city from this potential. External trips were made



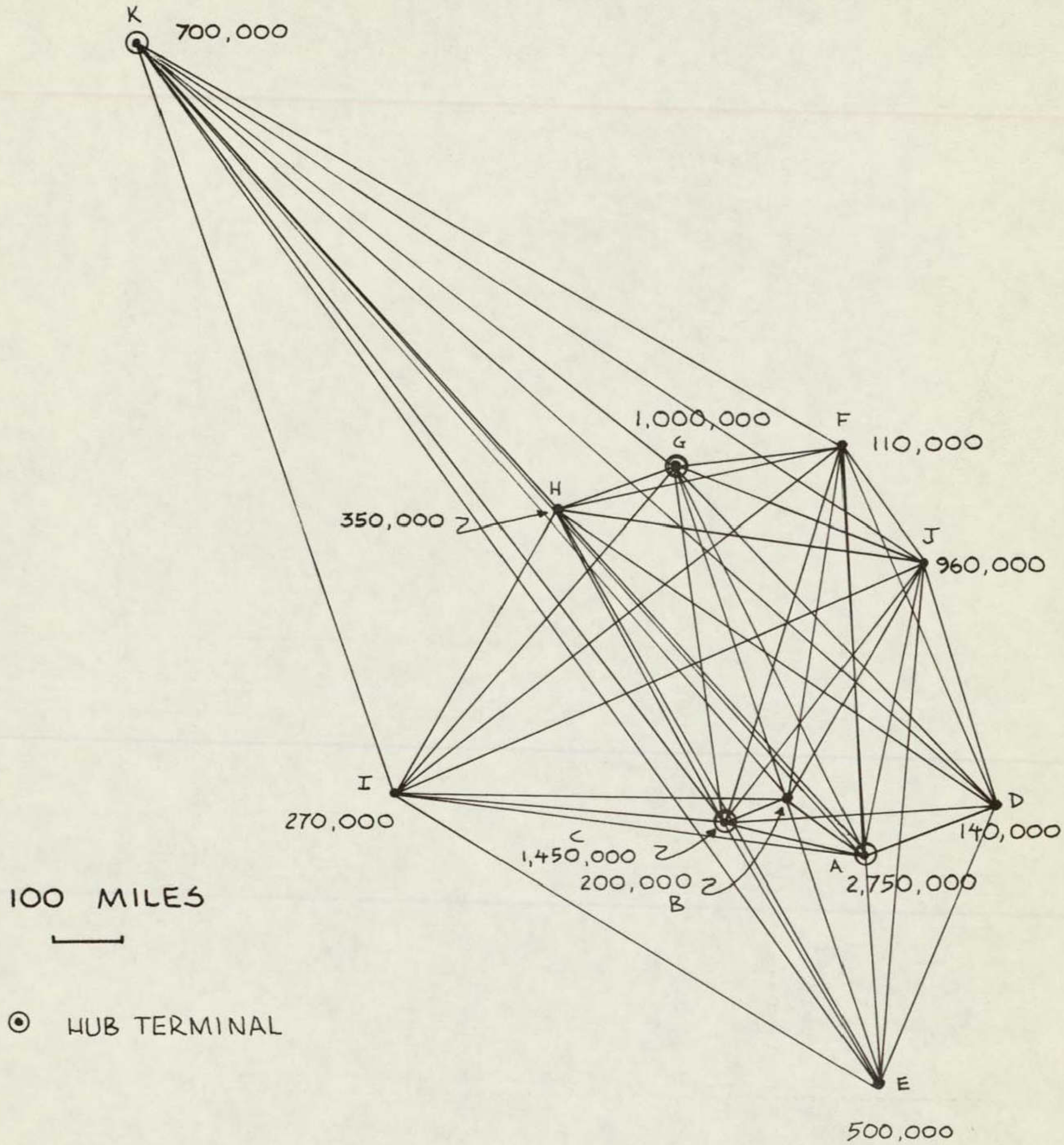
COMPARISON OF POPULATION DISTRIBUTIONS OF SAMPLE AREA AND DEMAND MODEL DATA

Figure 3-A-5



SAMPLE AREA AND OVERALL CITY DEMAND DISTRIBUTIONS

Figure 3-A-6



A SCALE DRAWING OF AREA SELECTED FOR STUDY

Figure 3-A-7

through regional hubs thus eliminating the necessity of connecting every city to external destinations. A further explaination of this will be found in Appendix 3-B-2.

3-A-5 Computer Printout

The following computer printout is the actual Demand Model written in the Fortran V computer language.

```
C
C         THIS PROGRAM WILL TAKE THE 1960 POPULATION AND THE 1950-1960
C      INCREASE AND PROJECT THE POPULATION FOR 1970,1980,1990, AND 2000.
C      IT WILL CALCULATE THE DISTANCE BETWEEN EACH CITY PAIR AND THEN
C      ESTIMATE AIR TRAFFIC DEMAND BETWEEN EACH CITY PAIR.
C
C      THE FIRST DATA CARD TELLS WHAT IS THE MAXIMUM NUMBER OF CITIES TO
C      BE CONSIDERED IN THIS RUN.
       READ(5,10) NMAX
    10 FORMAT (I3)
       DIMENSION CITYDT(144,8), USPOP(6), POPPRJ(144,6,3), CSUS(6),
      1BPRJ(144,6)
C      THE SECOND THROUGH N+1 DATA CARDS GIVE DATA ON CITY NAME AND
C      NUMBER AS WELL AS POPULATION, POPULATION INCREASE, LATITUDE,
C      LONGITUDE AND INCOME LEVEL.   ATTRACTIVENESS HAS BEEN OMITTED
C      FOR FIRST RUN INFORMATION.
   101 READ(5,11) N, (CITYDT(N,I),I=1,8)
    11 FORMAT (I3,21XF9.0,F7.3,F4.0,F3.0,F5.0,F3.0,F6.0,F6.0)
       CITYDT(N,3) = CITYDT(N,3)+ CITYDT(N,4)/60.0
       CITYDT(N,5) = CITYDT(N,5)+ CITYDT(N,6)/60.0
       IF (N.LT.NMAX) GO TO 101
C      ONCE THE DATA ON EACH AREA HAS BEEN READ THE PROJECTED POPULATION
C      FOR THE U.S.A. IS NECESSARY.  LAST DATA CARD
       READ(5,12) (USPOP(I),I=1,6)
    12 FORMAT (6F10.1)
C      THE NEXT SECTION WILL PROJECT THE POPULATION OF EACH CITY BY
C      THREE METHODS: ARITHMETIC, RATIO AND GEOMETRIC.  THIS DATA IS
C      STORED IN 'POPPRJL J' WHICH IS A THREE DIMENSIONAL ARRAY.  THE
C      FIRST SUBSCRIPT IS THE CITY NUMBER, THE SECOND THE TIME PERIODS,
C      AND THE THIRD THE PROJECTION METHOD (1=ARITH,2=RATIO,3=GEOMETRIC)
       WRITE(6,15)
    15 FORMAT(1H1,34HTHIS IS THE POPULATION PROJECTIONS)
       DO 109 N=1,NMAX
       DO 102 I=1,3
       POPPRJ(N,1,I) = CITYDT(N,1) / (1 + CITYDT(N,2))
   102 POPPRJ(N,2,I) = CITYDT(N,1)
       AINCP = POPPRJ(N,1,1) * CITYDT(N,2)
       GINCP = 1.0 + CITYDT(N,2)
       DO 103 J=1,2
   103 CSUS(J) = (POPPRJ(N,J,2) / USPOP(J)) / 1000.0
       RINCCS = CSUS(2) - CSUS(1)
       DO 104 J=3,6
       POPPRJ(N,J,1) = POPPRJ(N,J-1,1) + AINCP
       CSUS(J) = CSUS(J-1) + RINCCS
       POPPRJ(N,J,2) = CSUS(J) * USPOP(J) * 1000.0
   104 POPPRJ(N,J,3) = POPPRJ(N,J-1,3) * GINCP
       DO 108 J=2,6
C      THIS SECTION TAKES THE THREE PROJECTIONS OF POPULATION AND SELECTS
C      A BEST ESTIMATE.  IF THE RATIO PROJECTION IS BETWEEN THE OTHER TWO,
C      IT IS SELECTED, OTHERWISE 1/3 OF THE DIFFERENCE BETWEEN THE ARITH.
C      AND GEOM. IS ADDED TO THE ARITHMETIC FOR THE BEST ESTIMATE.
       IF (POPPRJ(N,J,2) - POPPRJ(N,J,1)) 105,106,107
   105 BPRJ(N,J) = POPPRJ(N,J,1) + 0.333 * (POPPRJ(N,J,3)-POPPRJ(N,J,1))
       GO TO 108
   106 CONTINUE
       IF (J.EQ.2) GO TO 107
```

```
      GO TO 105
  107 BPRJ(N,J) = POPPRJ(N,J,2)
  108 CONTINUE
  109 CONTINUE
C     STATEMENTS 108 THROUGH, BUT NOT INCLUDING 109, CAN BE REMOVED
C     ONCE PROGRAM HAS BEEN RUN SATISFACTORALY.
C
C
      DIMENSION DIST(144,144),                    TRVLIN( 61,144)
C     THIS SECTION OF PROGRAM CALCULATES THE GREAT CIRCLE DISTANCE
C     BETWEEN CITY PAIRS BASED ON LATITUDES AND LONGITUDES.
      WRITE(6,16)
   16 FORMAT(1H1,39HTHIS IS A SAMPLE OF THE DISTANCE OUTPUT)
      DO 311 I=1,NMAX
      DO 310 J=I,NMAX
      IF (J-I) 302,302,303
  302 DIST(I,J) = 0.0
      GO TO 310
  303 IF (CITYDT(I,5) - CITYDT(J,5)) 305,304,305
  304 DIST(I,J) = ABS(CITYDT(I,3) - CITYDT(J,3)) * 60.0 / 1.17
      GO TO 310
  305 IF (CITYDT(I,3) - CITYDT(J,3)) 307,306,308
  306 RADAOB = ABS(CITYDT(I,5) - CITYDT(J,5)) * 0.01745
      OA = 3438.0 * COS(CITYDT(I,3)  * 0.01745)
      AB = 2.0 * OA * SIN(RADAOB / 2.0)
      AOB = 2.0 * ASIN((0.5 * AB)/(3438.0))
      DIST(I,J) = AOB * 57.296 * 60.0 / 1.17
      GO TO 310
  307 ALAT = CITYDT(I,3)
      ALONG = CITYDT(I,5)
      BLAT = CITYDT(J,3)
      BLONG = CITYDT(J,5)
      GO TO 309
  308 ALAT = CITYDT(J,3)
      ALONG = CITYDT(J,5)
      BLAT = CITYDT(I,3)
      BLONG = CITYDT(I,5)
  309 P = ABS(ALONG - BLONG) * 0.01745
      PA = (90.0 - ALAT) * 0.01745
      PB = (90.0 - BLAT) * 0.01745
      PD = ATAN(COS(P)*TAN(PB))
      AD = PA - PD
      A = ATAN(TAN(P) * (SIN(PD)/SIN(AD)))
      AB = ASIN(SIN(P)* (SIN(PB)/SIN(A)))
      DIST(I,J) = AB * 57.296 * 60.0 / 1.17
  310 CONTINUE
      WRITE(6,17) I,(DIST(I,J) ,J=10,140,10)
   17 FORMAT (1H ,I3,14F8.0)
  311 CONTINUE
      DIMENSION KAUL(61)
      DO 350 KONT=1,61
  350 KAUL(KONT) = 0
      BLKDST = 50.0
      MPD1 = NMAX - 1
      DO 360 I = 1,MPD1
      MPD2 = I + 1
      DO 360 J = MPD2,NMAX
```

```
      UPLIMT = 50.0
      K = 1
  356 IF (DIST(I,J) - UPLIMT) 358, 358, 357
  357 UPLIMT = UPLIMT + BLKDST
      K = K + 1
      IF (UPLIMT.GT.3001.0) GO TO 358
      GO TO 356
  358 KAUL(K) = KAUL(K) + 1
  360 CONTINUE
      WRITE(6,351)
  351 FORMAT(1H1, 25H UPLIM  NO. CITIES
      UPLIMT = 50.0
      DO 365 I = 1,61
      UPLIMT = UPLIMT + BLKDST
  365 WRITE(6,352) UPLIMT, KAUL(I)
  352 FORMAT (1H ,F6.0, I8)
C
C     THIS SECTION PREDICTS DEMAND FOR EACH CITY PAIR BASED ON THE
C     GRAVITY MODEL:
      WRITE(6,18)
   18 FORMAT (1H1,31H THIS REPRESENTS DEMAND SUMMARY)
      MAXI = 0.0
      MINI = 1.0
      DO 410 I=1,NMAX
      IF (CITYDT(I,7) .GT.MAXI) MAXI = CITYDT(I,7)
      IF (CITYDT(I,7).LT.MINI) MINI = CITYDT(I,7)
  410 CONTINUE
      DO 445 N =2,6
      DO 411 K =1,61
  411 TRVLIN(K,N) = 0.0
      TTRVL = 0.0
      MPD1 = NMAX - 1
      DO 420 I = 1,MPD1
      MPD2 = I + 1
      DO 420 J = MPD2,NMAX
  415 FACTII= CITYDT(I,7) / MAXI
      FACTIJ= CITYDT(J,7) / MAXI
      FACTG = 0.5*(BPRJ(I,N)*BPRJ(J,N))/((DIST(I,J)**0.4)*(10.0**7.0))
      SLAC =-(0.007*(DIST(I,J)))**2.0
      FACTE = 1.0 - EXP(SLAC)
      FACTT = (1.1) ** (10.0*XN)
      XN = N-1
      DIST(J,I) = (FACTII + FACTIJ) * FACTG * FACTE * FACTT
      BLKDST = 50.0
      UPLIMT = 50.0
      K=1
      KMAX = 61
  416 IF (DIST(I,J) - UPLIMT) 418,418,417
  417 UPLIMT = UPLIMT + BLKDST
      K=K+1
      IF (UPLIMT.GT.3001.0) GO TO 418
      GO TO 416
  418 TRVLIN(K,N) = TRVLIN(K,N) + DIST(J,I)
      TTRVL = TTRVL + DIST(J,I)
  420 CONTINUE
      WRITE(6,21)
      DO 422 I=1,NMAX
```

```
      DO 421 J=1,NMAX
      IF (I.GT.J) CITYDT(I,8) = CITYDT(I,8) + DIST(I,J)/2.0
      IF (I.LT.J)CITYDT(I,8) = CITYDT(I,8) + DIST(J,I)/2.0
  421 CONTINUE
  422 WRITE(6,22) I, CITYDT(I,8)
   21 FORMAT (1H1,6X,16H CITY      DEMAND    )
   22 FORMAT (1H ,5X,I3,F10.0)
C     BEFORE INDEXING ON A NEW VALUE OF N WRITE DISTRIBUTIONS
      DIMENSION CUMTRV(100,6), PTRVL(100,6)
      CUMTRV(1,N) = TRVLIN(1,N) / TTRVL
      PTRVL(1,N) = TRVLIN(1,N) / TTRVL
      DO 430 K=2,KMAX
      PTRVL(K,N) = TRVLIN(K,N) / TTRVL
  430 CUMTRV(K,N) = CUMTRV(K-1,N) + PTRVL(K,N)
      WRITE(6,19)
   19 FORMAT (1H1, 14H   UPPER LIMIT, 6X,6HDEMAND,9X,7HPERCENT,10X,3HCUM
     1)
      UPLIMT = 0
      DO 445 K =1,KMAX
      UPLIMT = UPLIMT + 50.0
      WRITE(6,20) UPLIMT, TRVLIN(K,N), PTRVL(K,N), CUMTRV(K,N)
   20 FORMAT (6X,F5.0,F15.0,F15.3,F15.3)
  445 CONTINUE
      END
```

APPENDIX 3-B

This appendix details the route selection and loading procedure. Specific information pertinent to a more complete understanding of the route selection method is covered here. As such, an understanding of the general procedure is necessary. Therefore, this appendix should be read in conjunction with the appropriate portions of Chapter 3.

2-B-1 Inputs to the Model

In addition to those items mentioned in Chapter 3, some other parameters are input to the model. These are used to fine-tune the selection process, and to eliminate certain biases.

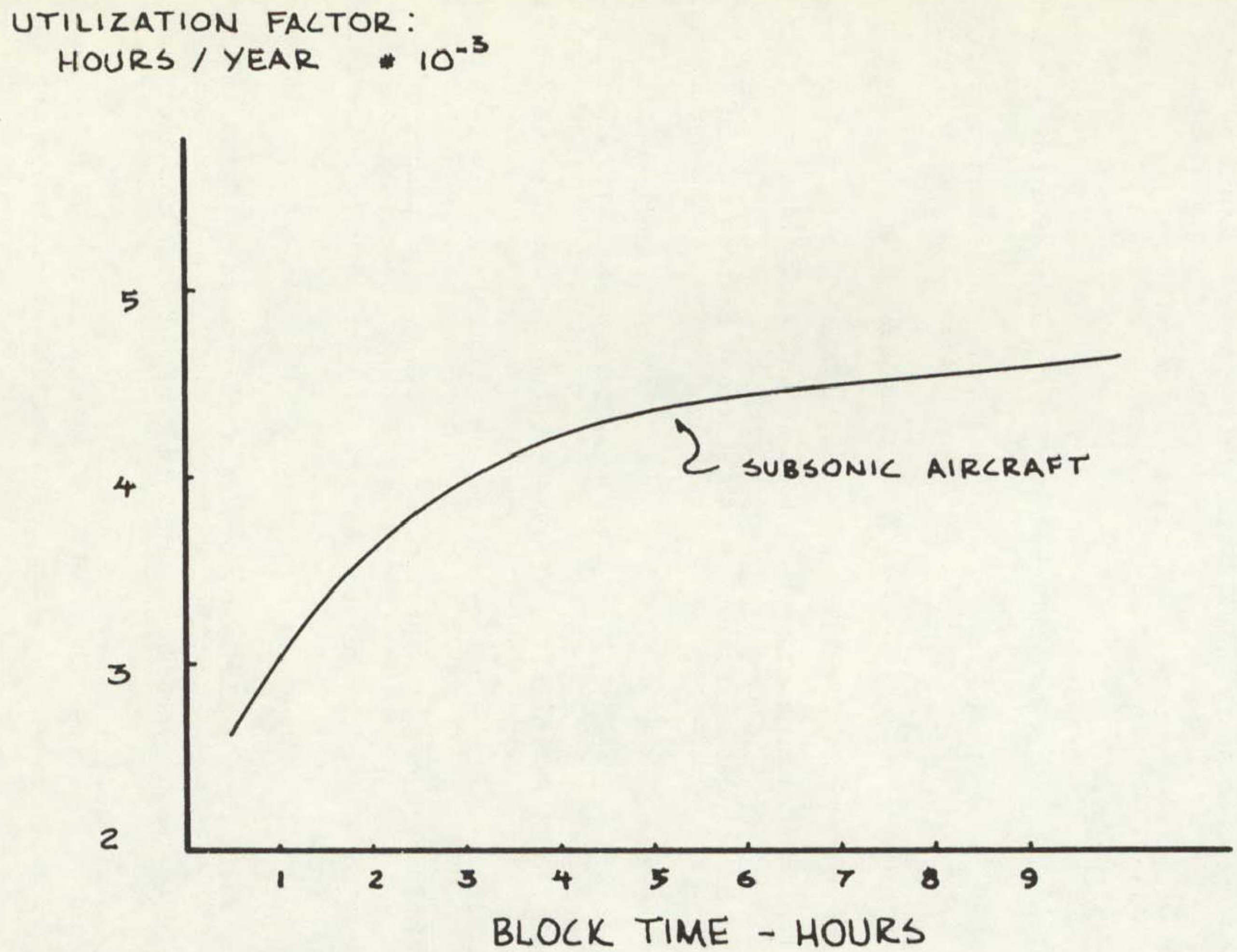
3-B-1.1 Aircraft Inputs

Several inputs regarding characteristics of the specific aircraft in the mix have been included to assist in calculations carried out in the route model.

A utilization curve (See Figure 3-B-1) was introduced. This allowed for the calculation of the fraction of an aircraft that would be necessary to fly a particular route. Since no scheduling considerations were undertaken, it was only necessary to total these fractions of airplanes needed to determine the total fleet size necessary to fly the network being considered.

A second additional input for each aircraft type was a minimum distance below which no assignment would be made. This was included to insure that the plane would be flown over ranges consistent with design considerations used in the aircraft design and cost models.

Finally, estimations of operating costs per flight mile were inputs. This was necessary to allow for the elimination of flights which might be carrying only a few passengers in a large capacity aircraft. Such situations



UTILIZATION FACTOR FOR VARIOUS BLOCK TIMES

Figure 3-B-1

might otherwise occur, in the case of a final assignment of an aircraft to a two or three legged flight, if it were not checked.

3-B-1.2 Route Inputs

The method by which the routes are determined for input to the model was not discussed in Chapter 3. At this point, a few comments are appropriate.

The route selection process was conducted using the demand volumes generated by the demand model. Those cities with large demands were connected by an appropriate route structure. Certain cities were also selected as hub airports, due to their regional characteristics. To the demand calculated for the hub city was added the demands for those feeder cities being served. External flights were also made from these hub cities. The routes selected were then re-evaluated and adjusted to account for the increased demands present.

In selecting the structure of each route, a combination of leg lengths was employed. By using legs of differing lengths, the greatest opportunity was available for each aircraft in the mix of those available to demonstrate its particular advantages in terms of capacity versus range. While the selection of the routes, and their structure, may appear to be somewhat arbitrary, the demand values generated made route selection reasonably deterministic.

3-B-2 The Route Model Algorithm

Some additional comments regarding the algorithm itself are warranted The process of assigning a plane to a route is described in Chapter 3. Since the STOL craft are assigned first, all demand is reduced to less than a STOL plane load before the CTOL assignment process begins. If a small city is located within STOL range of the hub city, a STOL port may be all that is required at the smaller city, since STOL can accomodate all flights to and from it.

The route model calculated the fleet size required to allow for aircraft costing. In addition to this, the number of average daily operations for each city was obtained to assist in the consideration of the airport size and control equipment necessary. This calculation was not adjusted for general aviation and only included the commercial flights. This figure was increased to include external trip making.

3-B-3 Computer Printout

The following computer printout of the Route Model utilized is written in the Fortran V computer language.

```
      DIMENSION KAPL(100), CSPD(100), MRL(100), LDATA(100,10),
     1   MINRL(100), KSRL(100), KDIST(11,11), KDMD(11,11), MINRA(200),
     2   KROUTE(200,10), KROUTF(200,2), MAXRA(200), NCPAX(11), NCF(11),
     3   NSPAX(11), NSF(11), KFREQ(11,11), NPAXIJ(11,11), NSAVIJ(11,11),
     4   AFT(11,11),NCTAP(11), NPF(11,11), NSFIJ(11,11), NCFIJ(11,11),
     5  FUDGE(11), COSTR(     10), NOPHR(11)
  903 FORMAT (I1,I2)
  904 FORMAT (53H1PROGRAM TERMINATED IN READ SECTION OF AIRCRAFT FILES,/
     143HAN IMPROPER DATA IDENTIFIER WAS INCOUNTERED)
  905 FORMAT (I1,I3,I3,I3,I4,I2,11I4)
  906 FORMAT (67H1PROGRAM TERMINATED DO TO IMPROPER SEQUENCE OF AIRCRAFT
     1 DATA CARDS   )
  907 FORMAT (I1,I2)
  908 FORMAT (1H1,54HPROGRAM TERMINATED IN READ SECTION OF STUDY AREA FI
     1LES ,/ 40H AN IMPROPER IDENTIFIER WAS INCOUNTERED   )
  909 FORMAT (I1,I2,11I4)
  910 FORMAT (1H1,44H THE DISTANCE MATRIX CARDS ARE OUT OF ORDER )
  911 FORMAT (I1,I2,11I7)
  912 FORMAT (1H1,42H THE DEMAND MATRIX CARDS ARE OUT OF ORDER   )
  913 FORMAT (I1,I3)
  914 FORMAT (1H1,49HPROGRAM TERMINATED IN READ SECTION OF ROUTE FILES,/
     139H AN IMPROPER IDENTIFIER WAS INCOUNTERED )
  915 FORMAT (I1,I3,5I2)
  916 FORMAT (1H1,33HTHE ROUTE CARDS ARE NOT IN ORDER   )
  929 FORMAT(I2,I1,I2,7I5)
  930 FORMAT(I2,I3,5I5)
```

```
 931 FORMAT(I2,I3,I5,F8.3,I5,F8.3,F7.3)
 933 FORMAT(I2,I5,I5)
 935 FORMAT(1H1,44H AN ERROR OCCURED IN THE RUN DATA FILE       )
 936 FORMAT(I2,I3,I3,4X,I8,12X,I8,6X,I4)
 937 FORMAT(I2,1H,,I2,1H,,I3,1H,,I4,1H,)
 938 FORMAT(I1,I2,11F7.0)
 939 FORMAT(42H1 THIS IS A PRINTOUT OF THE AIRCRAFT FILE ,/52H   I.D.
    1CAP.    CSD   RANGE    DISTANCE-COST PAIRS  ,47X,11H MINRL  RWY  )
 940 FORMAT(I4,3I7,5X, 4(I5,I5,5X),5X,I6,I5)
 941 FORMAT(1H1,36HTHIS IS THE DISTANCE MATRIX FOR THE ,I2,8H CITIES. )
 942 FORMAT(1H ,I3,11I6)
 943 FORMAT(1H ,/,35H THIS IS THE DEMAND BETWEEN CITIES  ,/)
 945 FORMAT(13H1ROUTE FILES,/14H NO.  SEQUENCE,//)
 946 FORMAT(    I3,4I5,I5,I5)
 947 FORMAT(1H1, //11H RUN NUMBER,I3,///,14H PLANES IN MIX   ,
    1I5,5H AND ,I5,/,4X,8HQUANTITY,2X,I5,5X,I5,//,56H CITY AIRPORT  MAX
    2DY  OPS/HR  CONTROLS   RUNWAY LENGTH       )
 949 FORMAT(1H , /,22H CTOL  FRACTION CLASS ,20X22H STOL FRACTION CLASS
    1   ,/,I5,F10.5,I8,25X,I3,F10.5,I8)
 948 FORMAT(1H ,I4,I6,5X,I3,I8,8X,I1,I10)
 950 FORMAT(28H1CARDS FOR TERMINAL MODEL      )
 951 FORMAT(I5,I5,I6,I8)
 952 FORMAT(28H1CARDS FOR EFF.MODEL           )
 953 FORMAT(1H ,2I2,11I4,2I10,I2,I5)
 954 FORMAT(    2I2,11I4,2I10,I2,I5)
 955 FORMAT(35H   AVERAGE FLYING TIME FROM I TO J    )
 956 FORMAT(11F10.4)
 957 FORMAT(I2,I2,11F6.3)
 958 FORMAT(19H1 FREQUENCY MATRIX  )
 960 FORMAT(2H ,//,17H NO1 NPIM1 NAVRG1,20X17H NO2 NPIM2 NAVRG2,/,
    1I3,I6,I5,23X,I3,I6,I5)
 961 FORMAT(15H  FUDGE FACTORS  ,//,11F8.3)
 962 FORMAT (      6I10 )
 963 FORMAT (7I10 )
 964 FORMAT ( 3I10,F10.5, I10)
 965 FORMAT(6I10)
 966 FORMAT(I5,I5,11I10)
 967 FORMAT(1H ,I3,I3,22I4)
 968 FORMAT(I2,I2,22I3)
 969 FORMAT(28H1CARDS FOR AIRCRAFT MODEL      )
 970 FORMAT(1H ,I2,I3,I4,I5)
 971 FORMAT(28H1CARDS FOR CONTROLS MODEL      )
 972 FORMAT(I2,I2,11I6)
 994 FORMAT(I5,11F10.3)
 995 FORMAT(I5,11I10)
 996 FORMAT(3I10)
 997 FORMAT(I5,I5,F10.1,4F10.4,4F10.2)
 998 FORMAT(12F10.3)
 999 FORMAT(12I10)
1000 FORMAT(1H1)
1001 FORMAT(1H )
     MAXDY = 6
     YHRS = 8760
     NP = 2
     NCLAS1 = 1
     NCLAS2 = 4
     GDMIN = 1
```

```
C
C     THIS SECTION READS THE AIRCRAFT FILE AND PRINTS THE DATA FOR
C     REVIEW
C
      WRITE(6,939)
      READ(5, 903) KAT, NDF
      IF (KAT.EQ.1) GO TO     2
    1 WRITE(6, 904)
      STOP 1108
    2 DO    3 I=1,NDF
      READ(5, 905) J, L, KAPL(I), MIKE    , MRL(I), LDATA(I,1),
     1(LDATA(I,K),K=2, 9), MINRL(I) , KSRL(I)
      CSPD(I) = MIKE
      IF (J.NE.1) GO TO     1
      WRITE(6,940) L, KAPL(I), MIKE    , MRL(I), (LDATA(I,K),K=2,9),
     1MINRL(I),KSRL(I)
      IF (L.EQ.30) WRITE(6,939)
      IF (L.EQ.I) GO TO     3
      WRITE(5, 906)
       STOP 1108
    3 CONTINUE
C
C     THIS SECTION READS THE FILES ON THE STUDY AREA.   THE DISTANCE
C     BETWEEN NODES IS READ FIRST, THEN THE DEMAND.
C
      READ(5, 907) KAT, NODE
      WRITE(6,941) NODE
      IF (KAT.EQ.2) GO TO     5
    4 WRITE(6, 908)
      STOP 1108
    5 DO    6 I=1,NODE
      READ(5, 909) J, K, (KDIST(I,I2),I2=1,NODE)
      WRITE(6,942)     K, (KDIST(I,I2),I2=1,NODE)
      IF (J.NE.2) GO TO     4
      IF (KDIST(I,I).EQ.0) GO TO     6
      WRITE(6, 910)
      STOP 1108
    6 CONTINUE
      WRITE(6,943)
      DO    7 I=1,NODE
      READ(5, 911) J, K, (KDMD(I,I2),I2=1,NODE)
      WRITE(6,942)     K, (KDMD(I,I2),I2=1,NODE)
      IF (J.NE.2) GO TO     4
      IF (KDMD(I,I).EQ.0) GO TO     7
      WRITE(6, 912)
      STOP 1108
    7 CONTINUE
C
C     FUDGE IS AN ARRAY OF FACTORS TO ADJUST TRAVEL FROM CERTAIN NODES
C     TO THE EXPECTED MAGNITUDE
C
      READ(5, 938) J,K,(FUDGE(I),I=1,NODE)
      WRITE(6,961) (FUDGE(I),I=1,11)
C
C     THIS SECTION READS INFORMATION ON THE POSSIBLE ROUTES.
C
      READ(5, 913) KAT, MAXR
```

```
      IF (KAT.EQ.3) GO TO    9
    8 WRITE(6, 914)
      STOP 1108
    9 KONT = 1
      DO   12 I=1,MAXR
      IF (KONT.EQ. 1) WRITE(6,945)
      READ(5, 915) J, K, (KROUTE(I,I2),I2=1,5)
      NAUX = KROUTE(I,1) + 1
      IF(J.NE.3) GO TO  8
      IF (K.EQ.I) GO TO    10
      WRITE(6, 916)
      STOP 1108
   10 MINRA(I) = 9999
      NOM = KROUTE(I,1) - 1
      MAXRA(I) = 0
      DO   11 J=1,NOM
      ITHN = KROUTE(I,J+1)
      JTHN = KROUTE(I,J+2)
      IF (KDIST(ITHN,JTHN).LT.MINRA(I)) MINRA(I) = KDIST(ITHN,JTHN)
   11 IF (KDIST(ITHN,JTHN).GT.MAXRA(I)) MAXRA(I) = KDIST(ITHN,JTHN)
      KONT = KONT + 1
      IF (KONT.EQ.50) KONT = 1
      WRITE(6,946)     K, (KROUTE(I,I2),I2=2,NAUX),MINRA(I),MAXRA(I)
   12 CONTINUE
   14 CONTINUE
C
C     THIS SECTION READS DATA ON SPECIFIC RUNS.  IT IS ASSUMED THAT
C     THERE ARE TWO PLANES IN THE MIX -- ONE CTOL (NO1) AND ONE STOL
C     (NO2).  THE PROGRAM WILL CONTINUE TO CYCLE UNTIL THE LAST DATA
C     CARD IS READ AND AN ERROR MESSAGE APPEARS - 947.
C
      KRUNNO = 1
   15 READ(5,933) KAT, NO1, NO2
      IF (KAT.NE.10) GO TO 55
      PIM1 = 0
      PIM2 = 0
      KDST1 = 0
      KDST2 = 0
      DO 16 I=1,11
      NSF(I) = 0
      NCF(I) = 0
      NCPAX(I) = 0
      NSPAX(I) = 0
      DO  16 J=1,11
      NSAVIJ(I,J) = 0
      AFT(I,J) = 0
      KFREQ(I,J) = 0
      NPAXIJ(I,J) = KDMD(I,J)
      NSFIJ(I,J) = 0
      NCFIJ(I,J) = 0
   16 CONTINUE
      DO 17 I=1,MAXR
      KROUTF(I,1) = 0
      KROUTF(I,2) = 0
   17 CONTINUE
C
C     THE FIRST STEP IS TO PLACE STOL PLANES ON ALL POSSIBLE ROUTES
```

```
C     THAT HAVE ENOUGH DEMAND TO FILL THE PLANE TO 80 PER CENT OF
C     CAPACITY.
C
      X = KAPL(NO2)
      LOAD2 = 0.6 * X
      DO 100 KTHR=1,MAXR
      IF (MRL(NO2).LT.MAXRA(KTHR)) GO TO 100
      IF (KROUTE(KTHR,1).NE.2) GO TO 100
      ITHN = KROUTE(KTHR,2)
      JTHN = KROUTE(KTHR,3)
      IF (NPAXIJ(ITHN,JTHN).LE.LOAD2) GO TO 100
      NUM = NPAXIJ(ITHN,JTHN)/LOAD2
      KDST2 = KDIST(ITHN,JTHN) * NUM * 2 + KDST2
      KROUTF(KTHR,2) = KROUTF(KTHR,2) + NUM * 2
      NPAXIJ(ITHN,JTHN) = NPAXIJ(ITHN,JTHN) - NUM * LOAD2
      NPAXIJ(JTHN,ITHN) = NPAXIJ(JTHN,ITHN) - NUM * LOAD2
      KFREQ(ITHN,JTHN) = KFREQ(ITHN,JTHN) + NUM
      KFREQ(JTHN,ITHN) = KFREQ(JTHN,ITHN) + NUM
      NSPAX(ITHN) = NSPAX(ITHN) + NUM * LOAD2
      NSPAX(JTHN) = NSPAX(JTHN) + NUM * LOAD2
      NSF(ITHN) = NSF(ITHN) + NUM * 2
      NSF(JTHN) = NSF(JTHN) + NUM * 2
      NSAVIJ(ITHN,JTHN) = NSAVIJ(ITHN,JTHN) + NUM * KAPL(NO2)
      NSAVIJ(JTHN,ITHN) = NSAVIJ(JTHN,ITHN) + NUM * KAPL(NO2)
      DIST  = KDIST(ITHN,JTHN)
      L = NO2
      A1 = (DIST-100.0)
      A2 = A1 / CSPD(L)
      BTYME = A2 + 0.6
      IF (BTYME.GT.2.0) GO TO 95
      UTIL1  = (1586.6 + 1673.3*BTYME - 316.8*BTYME**2.0) / YHRS
      GO TO 99
   95 IF (BTYME.GT.3.0) GO TO 96
      UTIL1  = (2800.0 + 400.0*BTYME) / YHRS
      GO TO 99
   96 IF (BTYME.GT.4.0) GO TO 97
      UTIL1  = (3400.0 + 200.0*BTYME) / YHRS
      GO TO 99
   97 IF (BTYME.GT.6.0) GO TO 98
      UTIL1  = (3800.0 + 100.0*BTYME) / YHRS
      GO TO 99
   98 UTIL1  = (4100.0 +  50.0*BTYME) / YHRS
   99 PIM2 = PIM2 + 2.0 * NUM * (BTYME/UTIL1)/24.0
      AUX = NUM
      AFT(ITHN,JTHN) = AFT(ITHN,JTHN) + AUX * BTYME
      AFT(JTHN,ITHN) = AFT(JTHN,ITHN) + AUX * BTYME
  100 CONTINUE
 3000 CONTINUE
C
C     THE  NEXT STEP IS TO PLACE CTOL PLANES ON ALL ROUTES POSSIBLE
C     THAT HAVE ENOUGH DEMAND STILL REMAINING TO FILL THE PLANE TO
C     80 PER CENT CAPACITY.
C
      X = KAPL(NO1)
      LOAD1 = 0.6 * X
      DO 200 KTHR=1,MAXR
      IF (MRL(NO1).LT.MAXRA(KTHR)) GO TO 200
```

```
      IF (MINRL(NO1).GT.MINRA(KTHR)) GO TO 200
      IF (KROUTE(KTHR,1).NE.2) GO TO 200
      ITHN = KROUTE(KTHR,2)
      JTHN = KROUTE(KTHR,3)
      IF (NPAXIJ(ITHN,JTHN).LE.LOAD1) GO TO 200
      NUM = NPAXIJ(ITHN,JTHN) / LOAD1
      KDST1 = KDIST(ITHN,JTHN) * NUM * 2 + KDST1
      KROUTF(KTHR,1) = KROUTF(KTHR,1) + NUM   * 2
      NPAXIJ(ITHN,JTHN) = NPAXIJ(ITHN,JTHN) - NUM * LOAD1
      NPAXIJ(JTHN,ITHN) = NPAXIJ(JTHN,ITHN) - NUM * LOAD1
      KFREQ(ITHN,JTHN) = KFREQ(ITHN,JTHN) + NUM
      KFREQ(JTHN,ITHN) = KFREQ(JTHN,ITHN) + NUM
      NCPAX(ITHN) = NCPAX(ITHN) + NUM * LOAD1
      NCPAX(JTHN) = NCPAX(JTHN) + NUM * LOAD1
      NCF(ITHN) = NCF(ITHN) + NUM * 2
      NCF(JTHN) = NCF(JTHN) + NUM * 2
      NSAVIJ(ITHN,JTHN) = NSAVIJ(ITHN,JTHN) + NUM * KAPL(NO1)
      NSAVIJ(JTHN,ITHN) = NSAVIJ(JTHN,ITHN) + NUM * KAPL(NO1)
      DIST  = KDIST(ITHN,JTHN)
      L = NO1
      A1 = (DIST-100.0)
      A2 = A1 / CSPD(L)
      BTYME = A2 + 0.6
      IF (BTYME.GT.2.0) GO TO 195
      UTIL1  = (1586.6 + 1673.3*BTYME - 316.8*BTYME**2.0) / YHRS
      GO TO  199
  195 IF (BTYME.GT.3.0) GO TO 196
      UTIL1  = (2800.0 + 400.0*BTYME) / YHRS
      GO TO 199
  196 IF (BTYME.GT.4.0) GO TO 197
      UTIL1  = (3400.0 + 200.0*BTYME) / YHRS
      GO TO 199
  197 IF (BTYME.GT.6.0) GO TO 198
      UTIL1  = (3800.0 + 100.0*BTYME) / YHRS
      GO TO 199
  198 UTIL1  = (4100.0 +  50.0*BTYME) / YHRS
  199 PIM1 = PIM1 + 2.0 * NUM * (BTYME/UTIL1)/24.0
      AUX = NUM
      AFT(ITHN,JTHN) = AFT(ITHN,JTHN) + AUX * BTYME
      AFT(JTHN,ITHN) = AFT(JTHN,ITHN) + AUX * BTYME
  200 CONTINUE
C
C     STOL CRAFT ARE THEN PLACED ON ALL ROUTES THAT STILL HAVE DEMAND
C     AND CAN BE FLOWN FOR LESS THAN ONE DOLLAR PER REV. SEAT MILE.
C
      COSTR(2) = LDATA(NO2,3)
      COSTR(1) = LDATA(NO2,2)
      COSTR(3) = LDATA(NO2,4)
      COSTR(4) = LDATA(NO2,5)
      COSTR(5) = LDATA(NO2,6)
      COSTR(6) = LDATA(NO2,7)
      COSTR(7) = LDATA(NO2,8)
      COSTR(8) = LDATA(NO2,9)
      DO 300 KTHR=1,MAXR
      IF (MRL(NO2).LT.MAXRA(KTHR)) GO TO 300
      IF (KROUTE(KTHR,1).NE.2) GO TO 250
      ITHN = KROUTE(KTHR,2)
```

```
      JTHN = KROUTE(KTHR,3)
      DIST1 = KDIST(ITHN,JTHN)
      I = 1
  201 IF (COSTR(I).GT.DIST1) GO TO 202
      I = I + 2
      GO TO 201
  202 CST = COSTR(I+1) * DIST1
      EFF = NPAXIJ(ITHN,JTHN) * KDIST(ITHN,JTHN) + 1
      GOODNS = CST / EFF
      IF (GDMIN.LT.GOODNS) GO TO 300
      NUM = 1
      KDST2 = KDST2 + NUM * KDIST(ITHN,JTHN) * 2
      KROUTF(KTHR,2) = KROUTF(KTHR,2) + 2
      KFREQ(ITHN,JTHN) = KFREQ(ITHN,JTHN) + 1
      KFREQ(JTHN,ITHN) = KFREQ(JTHN,ITHN) + 1
      NSPAX(ITHN) = NSPAX(ITHN) + NUM * NPAXIJ(ITHN,JTHN)
      NSPAX(JTHN) = NSPAX(JTHN) + NUM * NPAXIJ(JTHN,ITHN)
      NPAXIJ(ITHN,JTHN) = 0
      NPAXIJ(JTHN,ITHN) = 0
      NSF(ITHN) = NSF(ITHN) + 2
      NSF(JTHN) = NSF(JTHN) + 2
      NSAVIJ(ITHN,JTHN) = NSAVIJ(ITHN,JTHN) + KAPL(NO2)
      NSAVIJ(JTHN,ITHN) = NSAVIJ(JTHN,ITHN) + KAPL(NO2)
      DIST1 = KDIST(ITHN,JTHN)
      L = NO2
      BTYME = (DIST1 - 100.0) / CSPD(L)    + 0.6
      IF (BTYME.GT.2.0) GO TO 245
      UTIL1  = (1586.6 + 1673.3*BTYME - 316.8*BTYME**2.0) / YHRS
      GO TO 249
  245 IF (BTYME.GT.3.0) GO TO 246
      UTIL1  = (2800.0 + 400.0*BTYME) / YHRS
      GO TO 249
  246 IF (BTYME.GT.4.0) GO TO 247
      UTIL1  = (3400.0 + 200.0*BTYME) / YHRS
      GO TO 249
  247 IF (BTYME.GT.6.0) GO TO 248
      UTIL1  = (3800.0 + 100.0*BTYME) / YHRS
      GO TO 249
  248 UTIL1  = (4100.0 +  50.0*BTYME) / YHRS
  249 PIM2 = PIM2 + 2.0 * NUM * (BTYME/UTIL1)/24.0
      AUX = NUM
      AFT(ITHN,JTHN) = AFT(ITHN,JTHN) + AUX * BTYME
      AFT(JTHN,ITHN) = AFT(JTHN,ITHN) + AUX * BTYME
      GO TO 300
  250 ITHN = KROUTE(KTHR,2)
      JTHN = KROUTE(KTHR,3)
      KTHN = KROUTE(KTHR,4)
      DIST1 = KDIST(ITHN,JTHN)
      DIST2 = KDIST(JTHN,KTHN)
      I = 1
      J = 1
  251 IF (COSTR(I).GT.DIST1) GO TO 252
      I = I + 2
      GO TO 251
  252 IF (COSTR(J).GT.DIST2) GO TO 253
      J = J + 2
      GO TO 252
```

```
253 CST = COSTR(I+1) * DIST1 + COSTR(J+1) * DIST2
    NPAX13 = NPAXIJ(ITHN,KTHN)
    NSAV12 = KAPL(NO2) - NPAX13
    IF (NSAV12.LT.NPAXIJ(ITHN,JTHN)) GO TO 270
    NPAX12 = NPAXIJ(ITHN,JTHN)
    GO TO 275
270 NPAX12 = NSAV12
275 NSAV23 = NSAV12
    IF ( NSAV23.LT.NPAXIJ(JTHN,KTHN)) GO TO 280
    NPAX23 = NPAXIJ(JTHN,KTHN)
    GO TO 285
280 NPAX23 = NSAV23
285 EFF = NPAX13 * KDIST(ITHN,KTHN) + NPAX12 * KDIST(ITHN,JTHN) + NPAX
   123 * KDIST(JTHN,KTHN) + 1
    GOODNS = CST / EFF
    IF (GDMIN.LT.GOODNS) GO TO 300
    NUM = 1
    KDST2 = KDST2 + KDIST(ITHN,JTHN) + KDIST(JTHN,KTHN)
    KROUTF(KTHR,2) = KROUTF(KTHR,2) + 1
    NPAXIJ(ITHN,JTHN) = NPAXIJ(ITHN,JTHN) - NPAX12
    NPAXIJ(ITHN,KTHN) = NPAXIJ(ITHN,KTHN) - NPAX13
    NPAXIJ(JTHN,KTHN) = NPAXIJ(JTHN,KTHN) - NPAX23
    KFREQ(ITHN,JTHN) = KFREQ(ITHN,JTHN) + 1
    KFREQ(ITHN,KTHN) = KFREQ(ITHN,KTHN) + 1
    KFREQ(JTHN,KTHN) = KFREQ(JTHN,KTHN) + 1
    NSPAX(ITHN) = NSPAX(ITHN) + NPAX12 + NPAX13
    NSPAX(JTHN) = NSPAX(JTHN)          + NPAX23
    NSF(ITHN) = NSF(ITHN) + 1
    NSF(JTHN) = NSF(JTHN) + 2
    NSF(KTHN) = NSF(KTHN) + 1
    NSAVIJ(ITHN,JTHN) = NSAVIJ(ITHN,JTHN) + KAPL(NO2)
    NSAVIJ(ITHN,KTHN) = NSAVIJ(ITHN,KTHN) + KAPL(NO2)
    NSAVIJ(JTHN,KTHN) = NSAVIJ(JTHN,KTHN) + KAPL(NO2)
    DIST1 = KDIST(ITHN,JTHN)
    L = NO2
    KI = ITHN
    KJ = JTHN
    KONT = 0
286 BTYME = (DIST1 - 100.0) / CSPD(L)   + 0.6
    IF (BTYME.GT.2.0) GO TO 287
    UTIL1  = (1586.6 + 1673.3*BTYME - 316.8*BTYME**2.0) / YHRS
    GO TO 291
287 IF (BTYME.GT.3.0) GO TO 288
    UTIL1  = (2800.0 + 400.0*BTYME) / YHRS
    GO TO 291
288 IF (BTYME.GT.4.0) GO TO 289
    UTIL1  = (3400.0 + 200.0*BTYME) / YHRS
    GO TO 291
289 IF (BTYME.GT.6.0) GO TO 290
    UTIL1  = (3800.0 + 100.0*BTYME) / YHRS
    GO TO 291
290 UTIL1  = (4100.0 +  50.0*BTYME) / YHRS
291 PIM2 = PIM2 +       NUM * (BTYME/UTIL1)/24.0
    AFT(KI,KJ) = AFT(KI,KJ) + DIST1 / CSPD(L)
    KONT = 1 + KONT
    DIST1 = KDIST(JTHN,KTHN)
    KI = JTHN
```

```
      KJ = KTHN
      IF (KONT.EQ.1) GO TO 286
  300 CONTINUE
 4000 CONTINUE
C
C     CTOL CRAFT ARE THEN PLACED ON ALL ROUTES THAT STILL HAVE DEMAND
C     AND CAN BE FLOWN FOR LESS THAN ONE DOLLAR PER REV. SEAT MILE.
C
      COSTR(1) = LDATA(NO1,2)
      COSTR(2) = LDATA(NO1,3)
      COSTR(3) = LDATA(NO1,4)
      COSTR(4) = LDATA(NO1,5)
      COSTR(5) = LDATA(NO1,6)
      COSTR(6) = LDATA(NO1,7)
      COSTR(7) = LDATA(NO1,8)
      COSTR(8) = LDATA(NO1,9)
      DO 400 KTHR=1,MAXR
      IF (MRL(NO1).LT.MAXRA(KTHR)) GO TO 400
      IF (KROUTE(KTHR,1).NE.2) GO TO 350
      ITHN = KROUTE(KTHR,2)
      JTHN = KROUTE(KTHR,3)
      DIST1 = KDIST(ITHN,JTHN)
      I = 1
  301 IF (COSTR(I).GT.DIST1) GO TO 302
      I = I + 2
      GO TO 301
  302 CST = COSTR(I+1) * DIST1
      EFF = NPAXIJ(ITHN,JTHN) * KDIST(ITHN,JTHN) + 1
      GOODNS = CST / EFF
      IF (GDMIN.LT.GOODNS) GO TO 400
      NUM = 1
      KDST1 = KDST1 + NUM * KDIST(ITHN,JTHN) * 2
      KROUTF(KTHR,1) = KROUTF(KTHR,1) + 2
      NCPAX(ITHN) = NCPAX(ITHN) + NUM * NPAXIJ(ITHN,JTHN)
      NCPAX(JTHN) = NCPAX(JTHN) + NUM * NPAXIJ(JTHN,ITHN)
      NPAXIJ(ITHN,JTHN) = 0
      NPAXIJ(JTHN,ITHN) = 0
      NCF(ITHN) = NCF(ITHN) + 2
      NCF(JTHN) = NCF(JTHN) + 2
      NSAVIJ(ITHN,JTHN) = NSAVIJ(ITHN,JTHN) + KAPL(NO1)
      NSAVIJ(JTHN,ITHN) = NSAVIJ(JTHN,ITHN) + KAPL(NO1)
      DIST1 = KDIST(ITHN,JTHN)
      KFREQ(ITHN,JTHN) = KFREQ(ITHN,JTHN) + 1
      KFREQ(JTHN,ITHN) = KFREQ(JTHN,ITHN) + 1
      L = NO1
      BTYME = (DIST1 - 100.0) / CSPD(L)   + 0.6
      IF (BTYME.GT.2.0) GO TO 345
      UTIL1  = (1586.6 + 1673.3*BTYME - 316.8*BTYME**2.0) / YHRS
      GO TO 349
  345 IF (BTYME.GT.3.0) GO TO 346
      UTIL1  = (2800.0 + 400.0*BTYME) / YHRS
      GO TO 349
  346 IF (BTYME.GT.4.0) GO TO 347
      UTIL1  = (3400.0 + 200.0*BTYME) / YHRS
      GO TO 349
  347 IF (BTYME.GT.6.0) GO TO 348
      UTIL1  = (3800.0 + 100.0*BTYME) / YHRS
```

```
      GO TO 349
  348 UTIL1  = (4100.0 +  50.0*BTYME) / YHRS
  349 PIM1 = PIM1 + 2.0 * NUM * (BTYME/UTIL1)/24.0
      AUX = NUM
      AFT(ITHN,JTHN) = AFT(ITHN,JTHN) + AUX * BTYME
      AFT(JTHN,ITHN) = AFT(JTHN,ITHN) + AUX * BTYME
      GO TO 400
  350 ITHN = KROUTE(KTHR,2)
      JTHN = KROUTE(KTHR,3)
      KTHN = KROUTE(KTHR,4)
      DIST1 = KDIST(ITHN,JTHN)
      DIST2 = KDIST(JTHN,KTHN)
      I = 1
      J = 1
  351 IF (COSTR(I).GT.DIST1) GO TO 352
      I = I + 2
      GO TO 351
  352 IF (COSTR(J).GT.DIST2) GO TO 353
      J = J + 2
      GO TO 352
  353 CST = COSTR(I+1) * DIST1 + COSTR(J+1) * DIST2
      NPAX13 = NPAXIJ(ITHN,KTHN)
      NSAV12 = KAPL(NO1) - NPAX13
      IF (NSAV12.LT.NPAXIJ(ITHN,JTHN)) GO TO 370
      NPAX12 = NPAXIJ(ITHN,JTHN)
      GO TO 375
  370 NPAX12 = NSAV12
  375 NSAV23 = NSAV12
      IF ( NSAV23.LT.NPAXIJ(JTHN,KTHN)) GO TO 380
      NPAX23 = NPAXIJ(JTHN,KTHN)
      GO TO 385
  380 NPAX23 = NSAV23
  385 EFF = NPAX13 * KDIST(ITHN,KTHN) + NPAX12 * KDIST(ITHN,JTHN) + NPAX
     123 * KDIST(JTHN,KTHN) + 1
      GOODNS = CST / EFF
      IF (GDMIN.LT.GOODNS) GO TO 400
      NUM = 1
      KDST1 = KDST1 + KDIST(ITHN,JTHN) + KDIST(JTHN,KTHN)
      KROUTF(KTHR,2) = KROUTF(KTHR,2) + 1
      NPAXIJ(ITHN,JTHN) = NPAXIJ(ITHN,JTHN) - NPAX12
      NPAXIJ(ITHN,KTHN) = NPAXIJ(ITHN,KTHN) - NPAX13
      NPAXIJ(JTHN,KTHN) = NPAXIJ(JTHN,KTHN) - NPAX23
      KFREQ(ITHN,JTHN) = KFREQ(ITHN,JTHN) + 1
      KFREQ(ITHN,KTHN) = KFREQ(ITHN,KTHN) + 1
      KFREQ(JTHN,KTHN) = KFREQ(JTHN,KTHN) + 1
      NCPAX(ITHN) = NCPAX(ITHN) + NPAX12 + NPAX13
      NCPAX(JTHN) = NCPAX(JTHN)          + NPAX23
      NCF(ITHN) = NCF(ITHN) + 1
      NCF(JTHN) = NCF(JTHN) + 2
      NCF(KTHN) = NCF(KTHN) + 1
      NSAVIJ(ITHN,JTHN) = NSAVIJ(ITHN,JTHN) + KAPL(NO1)
      NSAVIJ(ITHN,KTHN) = NSAVIJ(ITHN,KTHN) + KAPL(NO1)
      NSAVIJ(JTHN,KTHN) = NSAVIJ(JTHN,KTHN) + KAPL(NO1)
      DIST1 = KDIST(ITHN,JTHN)
      L = NO1
      KI = ITHN
      KJ = JTHN
```

```
      KONT = 0
  386 BTYME = (DIST1 - 100.0) / CSPD(L)    + 0.6
      IF (BTYME.GT.2.0) GO TO 387
      UTIL1  = (1586.6 + 1673.3*BTYME - 316.8*BTYME**2.0) / YHRS
      GO TO 391
  387 IF (BTYME.GT.3.0) GO TO 388
      UTIL1  = (2800.0 + 400.0*BTYME) / YHRS
      GO TO 391
  388 IF (BTYME.GT.4.0) GO TO 389
      UTIL1  = (3400.0 + 200.0*BTYME) / YHRS
      GO TO 391
  389 IF (BTYME.GT.6.0) GO TO 390
      UTIL1  = (3800.0 + 100.0*BTYME) / YHRS
      GO TO 391
  390 UTIL1  = (4100.0 +  50.0*BTYME) / YHRS
  391 PIM1 = PIM1 +        NUM * (BTYME/UTIL1)/24.0
      AFT(KI,KJ) = AFT(KI,KJ) + DIST1 / CSPD(L)
      KONT = 1 + KONT
      DIST1 = KDIST(JTHN,KTHN)
      KI = JTHN
      KJ = KTHN
      IF (KONT.EQ.1) GO TO 386
  400 CONTINUE
  500 CONTINUE
C
C     CALCULATIONS FOR THE NECESSARY PRINTOUTS
C
      NPIM1 = PIM1
      NPIM2 = PIM2
       NPMIT = PIM1 +PIM2
      DO 610 I=1,11
      AUX = NCPAX(I)
      NCPAX(I) = AUX * FUDGE(I) * 2
      AX = NSPAX(I)
      NSPAX(I) = AX * FUDGE(I) * 2
      NSF(I) = NSF(I) * 5
      NCF(I) = NCF(I) * 5
      NOPHR(I) = (NSF(I) + NCF(I)) / 24
  610 CONTINUE
      MSRL = KSRL(NO2)
      DO 650 I=1,11
      NSOP = NSF(I)
      NCOP = NCF(I)
      IF (NCOP.NE.0) GO TO 615
      NCTAP(I) = 6
      GO TO 650
  615 CONTINUE
      TOP = NCOP + NSOP
      IF (TOP.GT.1000.)      GO TO 625
      IF (NSOP.GT.300) GO TO 620
      NCTAP(I) = 1
      GO TO 650
  620 CONTINUE
      NCTAP(I) = 3
      GO TO 650
  625 IF (NCOP.GT.500) GO TO 630
      NCTAP(I) = 4
```

```
      GO TO 650
  630 IF (NSOP.GT.200) GO TO 635
      NCTAP(I) = 2
      GO TO 650
  635 NCTAP(I) = 5
  650 CONTINUE
      DO 690 I=1,11
      DO 690 J=1,11
      AUX = KFREQ(I,J)
      AFT(I,J) = AFT(I,J) / AUX
      NPF(I,J) = KDMD(I,J)
      IF (KDMD(1,J).GT.NSAVIJ(I,J)) NPF(I,J) = NSAVIJ(I,J)
  690 CONTINUE
      DO 700 KTHR=1,MAXR
      IF (KROUTE(KTHR,1).EQ.3) GO TO 695
      ITHN = KROUTE(KTHR,2)
      JTHN = KROUTE(KTHR,3)
      NSFIJ(ITHN,JTHN) = NSFIJ(ITHN,JTHN) + KROUTF(KTHR,2)
      NCFIJ(ITHN,JTHN) = NCFIJ(ITHN,JTHN) + KROUTF(KTHR,1)
      NSFIJ(JTHN,ITHN) = NSFIJ(JTHN,ITHN) + KROUTF(KTHR,2)
      NCFIJ(JTHN,ITHN) = NCFIJ(JTHN,ITHN) + KROUTF(KTHR,1)
      GO TO 700
  695 CONTINUE
      ITHN = KROUTE(KTHR,2)
      JTHN = KROUTE(KTHR,3 )
      KTHN = KROUTE(KTHR,4)
      NSFIJ(ITHN,JTHN) = NSFIJ(ITHN,JTHN) + KROUTF(KTHR,2)
      NCFIJ(ITHN,JTHN) = NCFIJ(ITHN,JTHN) + KROUTF(KTHR,1)
      NSFIJ(JTHN,KTHN) = NSFIJ(JTHN,KTHN) + KROUTF(KTHR,2)
      NCFIJ(JTHN,KTHN) = NCFIJ(JTHN,KTHN) + KROUTF(KTHR,1)
  700 CONTINUE
      KF1 = 0
      KF2 = 0
      DO 720 I=1,11
      DO 720 J=1,11
       KF1 = KF1 + NCFIJ(I,J)
      KF2 = KF2 + NSFIJ(I,J)
  720 CONTINUE
      NAVRG1 = KDST1 / KF1
      NAVRG2 = KDST2 / KF2
C
C     THE PRINT PUNCH SECTION WILL CYCLE THREE TIMES FOR EACH MIX THAT
C     IS RUN.  THIS IS DONE TO ALLOW THREE PACKAGES OF CONTROL EQUIP-
C     MENT TO BE TESTED
C
      DO 899 KPACK=1,3
C
C     DATA FOR THE CONTROLS MODEL IS PUNCHED FIRST.  THE I.D. NUMBER
C     IS 12 AND THERE SHOULD BE 33 CARDS PUNCHED.
C
      WRITE(6,971)
      KID = 12
      WRITE(7,929) KID, NP, NO1, NPIM1, NO2, NPIM2
      WRITE(6,962) KID,NP,NO1,NPIM1,NO2,NPIM2
       DO 810 I=1,11
      WRITE(6,963) KID,I,NCTAP(I),MAXDY,NOPHR(I),KPACK,MSRL
      WRITE(7,930) KID, I, NCTAP(I), MAXDY, NOPHR(I), KPACK, MSRL
```

```
      F1 = NCF(I) / (NCF(I) + NSF(I))
      F2 = 1.0 - F1
      WRITE(7,931) KID, I, NO1, F1, NCLAS1
      WRITE(7,931) KID, I, NO2, F2, NCLAS2
      WRITE(6,964) KID,I,NO1,F1,NCLAS1
      WRITE(6,964) KID,I,NO2,F2,NCLAS2
  810 CONTINUE
C
C     DATA FOR THE TERMINAL TIMES MODEL IS PUNCHED NEXT.  THE I.D.
C     NUMBER IS 13 AND THERE SHOULD BE 11 CARDS.
C
      KID = 13
      WRITE(6,950)
      DO 820 I=1,11
      WRITE(7,936) KID, NCTAP(I), I, NSPAX(I), NCPAX(I), MSRL
      WRITE(6,965) KID,NCTAP(I),I,NSPAX(I),NCPAX(I),MSRL
  820 CONTINUE
C
C     DATA FOR THE EFFECTIVENESS MODEL IS PUNCHED NEXT.  THE I.D.
C     NUMBER IS 14 AND THERE SHOULD BE 33 CARDS.
C
      KID = 14
      WRITE(6,952)
      DO 825 I=1,11
      WRITE(6,966) KID,I,(NPF(I,K),K=1,11)
  825 WRITE(7,972) KID, I, (NPF(I,K),K=1,11)
      WRITE(6,955)
      DO 830 I=1,11
      WRITE(6,956) KID,I,(AFT(I,J),J=1,11)
  830 WRITE(7,957) KID, I, (AFT(I,K), K=1,11)
      DO 835 I=1,11
      WRITE(6,953) KID,I,(KFREQ(I,J),J=1,11),NSPAX(I),NCPAX(I),NCTAP(I),
     1MSRL
      WRITE(7,954) KID,I,(KFREQ(I,J),J=1,11),NSPAX(I),NCPAX(I),NCTAP(I),
     1MSRL
  835 CONTINUE
      DO 840 I=1,11
      WRITE(6,967) KID,I,(NSFIJ(I,J),J=1,11),(NCFIJ(I,K),K=1,11)
  840 WRITE(7,968) KID,I,(NSFIJ(I,J),J=1,11),(NCFIJ(I,K),K=1,11)
C
C     DATA FOR AIRCRAFT COST MODEL IS PUNCHED LAST.  THE I.D. NUMBER
C     IS 15 AND THERE SHOULD BE 2 CARDS.
C
      KID = 15
      WRITE(7,937) KID, NO1, NPIM1, NAVRG1
      WRITE(6,970) KID,NO1,NPIM1,NAVRG1
      WRITE(7,937) KID, NO2, NPIM2, NAVRG2
      WRITE(6,970) KID,NO2,NPIM2,NAVRG2
      KRUNNO = KRUNNO + 1
  899 CONTINUE
      GO TO 15
   55 WRITE(6, 935)
      END
```

APPENDIX 4-A

URBAN LAND VALUE MODEL

The urban land value model has been tested in order to determine how well the model values compared with values obtained from independent observations. The relationships are shown in TABLE 4-A-1.

For Los Angeles, the table shows that mean high for the independent observation is 19.5% above the calculated estimate, and the independent mean low is 1.7% below the calculated estimate. The Seattle data comparisons indicate that the estimator calculations are low for the North, South, and East areas, but high for the West area.

For Washington, D.C. the estimator is low 2.8 miles, high at 4.1 miles, and varies with high and low estimates.

From this table, we can see that the estimator equation gives values that are considerably lower than those obtained by actual investigation.

LOCATION TESTED	ESTIMATOR EQUATION ($10^6/ACRE)	OTHER SOURCES ($10^6/ACRE) MEAN HI	MEAN LO	PERCENT DIFFERENCE (ESTIMATOR − OTHER) / ESTIMATOR MEAN HI	MEAN LO
Los Angeles, Calif. (1 mile from CBD)	0.942	1.126	0.926	− 19.5	+ 1.7
Seattle, Washington (1 mile from CBD)	0.925	N 0.120 E 0.160	S 0.274 W 0.022	N − 83 E − 72	S − 196 W + 76
Washington, D.C. (1) 2.8 miles* (2) 4.1 miles* (3) 11.9 miles* * from 17th and K Sts., N.W.	 0.072 0.049 0.019	 0.102 0.079 0.015 To	 0.020	 −41.6 +61.2 +21.5	 − 5.7

TABLE 4-A-1

APPENDIX 4-B

PROCESS TIME MODEL

4-B-1 Constant Time

The following table was used to determine the constant term in the process-time model:

Function	TIME (Min.) Arrive	TIME (Min.) Depart	Totals
ticket clearance*	---	8	8
baggage check-in	---	2	2
baggage claim	5	---	5
board plane**	10	10	20

*Ticket clearance time of 8 minutes is based on a service rate of 1 person (with reservation) every two minutes and a waiting line of 4 people.

**Board plane refers to both loading and unloading passengers

Constant term = average time = $\frac{35}{2}$ = 17.5 min.

4-B-2 Time from Auto to Terminal

A McDonnell Aircraft Corporation report presented a relationship between daily passengers (PAX) and size of parking lot area area (A_1) needed:

$$A_1 = 0.1 \text{ PAX } (280) \quad \text{Reference [2]}$$

Assuming a square parking lot, the length of a side (L) is:

$$L = [0.1 \text{ PAX } (280)].^{0.5} \text{ or } d_1 = 3.97 \text{ PAX}^{0.5}$$

Also, it can be shown that the average parker in this lot must travel 0.75L to get to the terminal, therefore, the average parker's walking distance (d_1) is:

$$t_1 = \frac{d_1}{220} = \frac{3.97\ PAX^{0.5}}{220} = 0.018\ PAX^{0.5}\ \text{min.}$$

4-B-3 Time to Get to Correct Gate Position

The McDonnell Report also developed a relationship for effective terminal floor area (A_2) based on the number of daily passengers:

$$A_2 = e^{4.427}\ PAX^{0.798}$$

Making the same assumptions as for the parking lot the passenger's terminal walking distance (d_2) is:

$$d_2 = 0.75\ [e^{4.427}\ PAX^{0.798}] = 6.87\ (PAX^{0.798})^{0.5}$$

The time walking to the correct gate ($+_2$) is:

$$t_2 = \frac{6.87\ (PAX^{0.798})^{0.5}}{220} = 0.031\ PAX^{0.4}$$

Combining these three parameters we get the total process time (PT):

$$PT = 17.5 + 0.018\ PAX^{0.5} + 0.031\ PAX^{0.4}$$

A plot of this relationship is presented below:

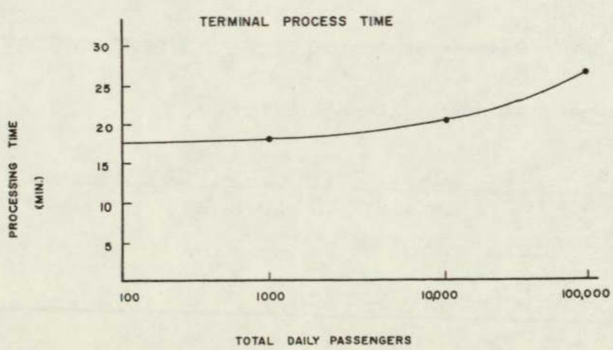


Figure 4-B-1

APPENDIX 4-C

List of Symbols

STOL Terminal Model

Symbol	Definition
A	Area of urban area in square miles
X	Distance from CBD to STOL port
ρ	Distance from S/CTOL to line denoting area of least distance to S/CTOL
Ps	Daily passengers at STOL
Pc	Daily passengers at CTOL
Psc	Daily passengers at S/CTOL
C	Conventional Airport
CS	Conventional Airport with STOL port
S	Independent STOL port

4-C-1 Access Distance

Assume a particular city would have one of six airport cases (See Figure 4.4). These cases are:

1. 2C
2. C
3. CS
4. CS + S
5. CS + S + C
6. S

Further assume urban areas to be square. The C and CS ports are located at the midpoint of one of the sides. For simplicity, the S ports in cases 4 and 5 are located on this line joining the C or CS port and the CBD. The CBD is assumed at the center of the square.

Assume persons move in Y direction then in X direction in all cases.

4-C-1.1 Case 1.

1. Total persons north of CBD = 0.35 Pc

2. " " south " " = 0.35 Pc

3. " " in " = 0.30 Pc

4. Y movement of persons north of CBD = 1/4L

5. " " " " south " " = 1/4L

6. " " " " in " = 0

where L = A

7. X movement of persons north of CBD = 1/2L

8. " " " " south " " = 1/2L

9. " " " " in " = 1/2L

Weighted average distance to CTOL (D_c) is:

$$D_c = \frac{0.35\ Pc\ (1/4L + 1/2L) + 0.35\ Pc\ (1/4L + 1/2L) + 0.30\ Pc\ (L1/2)}{Pc} = 0.675L$$

4-C-1.2 Case 2. As in Case 1.

1. 0.35 Pc
2. 0.35 Pc
3. 0.30 Pc
4. 1/4L
5. 1/4L — Dc = 0.5L
6. 0
7. 1/4L
8. 1/4L
9. 1/2L

$$D_c = \frac{0.35\ Pc\ (1/4L + 1/4L) + 0.35\ Pc\ (1/4L + 1/4L) + 0.30\ Pc\ (1/2L)}{Pc} = 0.5L$$

4-C-1.3 Case 3. As in Case 1.

Distance to S/CTOL = Dsc = 0.675 L

4-C-1.4 Case 4. Ds = distance to STOL

$\rho = 1/4L - 1/2X \qquad \triangle = 0.7\ (Ps + Psc)/A$

$A' = L\rho$

$Dsc = (\rho l/2 + Ll/4) = 3L/8 - X/4$

$$Ds = \{\frac{[(11L^2/16) + XL + 5X^2/4]\ 0.35(Ps + Psc)/L + /X/0.3(Ps + Psc)}{Ps + Psc + (\triangle L^2/4) + LX\triangle/2}\}$$

4-C-1.5 Case 5.

Ds is as in Case 4; Dsc + Dc is as in case 2

4-C-1.6 Case 6. Ds is as Dc in case 1.

4-C-2 Cost of Access

Total cost of access for a city (Ca) is: $Ca = K_1 \sum_{i=1}^{N} T_i P_i$

Where: K_1 = \$16.75/hr (See Section 4.2.3)

P_i = Passengers using port i

$T_i = 9.156\ D_i^{\ 0.59910}$ = Hours to particular port

D_i = Average distance in miles to particular port

N = Number of ports in city

4-C-3 Land Cost

Land Cost per acre (Cl) is: $\dfrac{844(Pa/1000)^{0.309} A^{0.971}}{(10X)^{0.867}}$

where: Pa = urban area population

$\bar{X}$ = Distance from CBD to STOL port

$\bar{A}$ = Area of urban area in square miles

4-C-4 Cost of STOL Terminal

By a search procedure, the point at which costs of structure, land, access, operations, and maintenance were minimized was found. This was done for a conventionally designed STOL port which is built on the ground; and a single monolithic structure which included terminal, hangers, parking and runways.

The basic design was for a runway length of 1350 feet. If the runway was over 1350 feet the appropriate costs were proportioned. A STOL structure was considered only if one runway was needed.

If only one runway minimize:

(1) $K_2Cd_1 + K_3(1.1\ Ct_1 + 60\ Cl) + K_4(Cn + Ca) + Fc$

(2) $K_2Cd_2 + K_3(1.1\ Ct_2 + 1.5\gamma Cl) + K_4(Cn + Ca) + Fc$

using least value of the two equations as cost. Otherwise minimize only (2).

Where: K_3 = Interest constant for design period

K_4 = Interest constant for construction period

K_5 = Interest constant for operations period

$Cd_1 = 0.04\ Ct_1$ = Design cost of monolithic terminal

$Cd_2 = 0.04\ Ct_2$ = Design cost of conventional terminal

Ct_1 = Construction cost of monolithic terminal =

$$(Psc + Ps - \triangle A')\ 49 + \frac{Lr}{1350}\ \$18,586,265$$

Ct_2 = Conventional terminal =

$$(Psc + Ps - \triangle A')63 + \frac{Lr}{1350}\ \$2,343,930$$

Lr = Length of STOL runway in feet

γ = Acres for terminal buildings and parking = $40 + \frac{7}{26402}(Ps + Psc - \triangle A')$

Ca = Access cost per year

Cn = Yearly operations and maintenance costs = $\$300.00 + \frac{\$830}{16}(Ps + Psc - \triangle A')$

Fc = cost of CTOL or S/CTOL facilities

APPENDIX 4-D

Computer Printout of the

CTOL - STOL Terminal Effectiveness Model written

in the FORTRAN IV Computer Language.

```
C * * * * THIS PROGRAM HAS PUNCH CARD OUTPUT * * * * * * * * * * * * *
C
C     STOL - CTOL TERMINAL COST EFFECTIVENESS MODEL
C     EFFECTIVENESS VERSION
C     DEVELOPED BY DASH, MULLEN, AND KASHUBA
C     PROGRAMMED BY DASH AND LEFTWICH
C     FOR AE / ME / EE 655-6  - COMPLEX SYSTEMS DESIGN
C
C     THE VARIABLES USED IN THIS PROGRAM ARE DEFINED AS FOLLOWS -
C
C         A = AREA OF CITY IN SQUARE MILES
C        AC = AREA SERVED BY THE CTOL TERMINAL
C       ACT = BASIC CTOL AIRPORT LAND
C       AK1 = COMPOUNDED DESIGN COST FACTOR ( 2.399 )
C       AK2 = COMPOUNDED CONSTRUCTION COST FACTOR ( 2.014 )
C       AK3 = COMPOUNDED OPERATIONS COST FACTOR ( 13.972 )
C        AL = SIDE OF CITY IN MILES
C     ALFCR = TOTAL LINEAR FEET OF CTOL RUNWAYS
C        AM = COUNTER
C      ANSR = NUMBER OF STOL RUNWAYS
C       AST = BASIC STOL AIRPORT LAND
C      AST1 = AREA REQUIRED FOR STOL TERMINAL
C      AST2 = MINIMUM STOL LAND AREA
C        BL = COUNTER
C        CA = TOTAL ACCESS COSTS TO STOL TERMINAL
C       CD1 = DESIGN COST OF STOL TERMINAL ( CT1 )
C       CD2 = DESIGN COST OF STOL TERMINAL ( CT2 )
C        CF = CONVERSION FACTOR - SQUARE FEET TO ACRES (43560)
C        CL = LAND COST FOR STOL TERMINAL
C        CN = OPERATIONS COST OF STOL TERMINAL
C       CTT = CTOL TRAVEL TIME
C       CT1 = TERMINAL COST OF STOL TERMINAL AND STRUCTURE PARKING
C       CT2 = TERMINAL COST STOL TERMINAL AND GROUND PARKING
C        DC = AVERAGE DISTANCE TO CTOL TERMINAL
C       DCP = DAILY CTOL PASSANGER DEMAND
C       DEN = DENSITY OF POPULATION OF TRIPS
C        DS = AVERAGE DISTANCE TO STOL TERMINAL
C       DSP = DAILY STOL PASSANGER DEMAND
C         E = NATURAL LOG BASE
C      EACT = EXCESS LAND (AREA) AVAILABLE AT CTOL
C      EAST = EXCESS LAND (AREA) AVAILABLE AT STOL
C        FC = CTOL ANNUAL COST FUNCTION - TOTAL
C       FCA = CTOL ANNUAL COST FOR 1 OR 2 STORY CTOL
C       FCB = CTOL ANNUAL COST FROM SUBROUTINE TERCOS
C       FCC = MINIMUM COST OF CTOL TERMINAL ( 1 OR 2 STORIES )
C       FCD = MINIMUM COST OF SECOND CTOL TERMINAL (CASE 5)
C         I = COUNTER
C        IA = AREA OF CITY IN SQUARE MILES
```

```
C      IACT = BASIC CTOL AIRPORT LAND
C      IAST = BASIC STOL AIRPORT LAND
C     ICASE = CASE NUMBER
C      ICTC = CTOL TERMINAL COST
C        ID = IDENTIFIER NUMBER
C      IDCP = DAILY CTOL PASSANGER DEMAND
C      IDNO = IDENTIFIER NUMBER
C      IDSP = DAILY STOL PASSANGER DEMAND
C       ID2 = IDENTIFIER NUMBER
C     IEACT = EXCESS LAND (AREA) AVAILABLE AT CTOL
C     IEAST = EXCESS LAND (AREA) AVAILABLE AT STOL
C     IGATC = GROUND ACCESS TIME AT CTOL
C     IGATS = GROUND ACCESS TIME AT STOL
C     IGPTC = GROUND PROCESS TIME AT CTOL
C     IGPTS = GROUND PROCESS TIME AT STOL
C      IPOP = CITY POPULATION
C      IRLS = RUNWAY LENGTH OF STOL RUNWAYS
C      ISTC = STOL TERMINAL COST
C         J = COUNTER
C     JCASE = CASE NUMBER
C         K = COUNTER
C         L = COUNTER
C      LFCR = TOTAL LINEAR FEET OF CTOL RUNWAYS
C         M = COUNTER
C         N = COUNTER (CITY NUMBER)
C        NA = CITY NUMBER
C       NA2 = CITY NUMBER
C      NSCT = NUMBER OF STORIES IN CTOL TERMINAL
C       NSR = NUMBER OF STOL RUNWAYS
C         P = SUM OF DSP AND DCP IN CASE 6
C       POP = CITY POPULATION
C         Q = HORIZONTAL DISTANCE OF STOL PASSANGERS TO CTOL
C        RD = RUNWAY LENGTH OF STOL RUNWAYS
C      IRLS = RUNWAY LENTH OF STOL RUNWAYS
C      SPAC = STOL PASSANGERS AT CTOL TERMINAL
C      SPAS = STOL PASSANGERS AT STOL TERMINAL
C       STT = STOL TRAVEL TIME
C      TACP = TOTAL ANNUAL CTOL PASSANGERS
C       TCT = TOTAL COST MINIMIZING VARIABLE
C      TCT1 = TOTAL COST FUNCTION - HIGH RISE STOL
C      TCT2 = TOTAL COST FUNCTION - GROUND LEVEL STOL
C      TCT3 = MINIMUM COST OF TCT1 AND TCT2
C      TCT4 = MINIMUM STOL COST (CASE 4)
C      TDCP = TOTAL DAILY CTOL PASSANGERS
C        VA = AVERAGE VALUE OF TIME PER HOUR $16.75
C         X = LOCATION OF STOL TERMINAL FROM THE CBD
C
      DIMENSION IPOP (11), IA (11), NA (11), ICASE (11), IDSP (11),
     1 IDCP (11), IRLS (11), RLS (11), ID (11), FCA (11)
      DIMENSION ID2 (11), NA2 (11), IACT (11), IAST (11), IEACT (11),
     1 IEAST (11), NSR (11), LFCR (11), TCT (100), FC1(100)
      COMMON TACP, SPAC,ANSR, POP, AL,ALFCR, ACT, EACT, NSCT, FCB, A
      DATA (IPOP (I),I=1,11) / 2750000, 200000, 1450000, 140000,
     1 500000, 110000, 10000000, 350000, 270000, 960000, 700000 /
      DATA (IA(I) , I=1,11) / 506, 27, 125, 31, 82, 53, 1030, 44,
     1 59, 144, 64 /
      DIMENSION I1(50,20), I2(50,20), I3(50,20), I4(50,20), I5(50,20),
     1I6(50,20), I10(50,20), I11(50,20), I12(50,20), I13(50,20),
```

```
     2I14(50,20), I15(50,20), I16(50,20), I17(50,20)
      DO 1000 J=1,9
      READ ( 5, 3)(I1(J,I), I2(J,I), I3(J,I), I4(J,I), I5(J,I),
     1I6(J,I), I=1,11 )
 1000 CONTINUE
      DO 2000 J=1,9
      READ ( 5,22) ( I10(J,I), I11(J,I), I12(J,I), I13(J,I), I14(J,I),
     1I15(J,I), I16(J,I), I17(J,I), I=1,11 )
 2000 CONTINUE
C
C     READ INPUT DATA FROM ROUTE MODEL
C
      DO 740 IREP = 1,9
      WRITE ( 6,  1) IREP
    1 FORMAT ( 1H1,  40H INPUT DATA TERMINAL EFFECTIVENESS MODEL  /
     1 11H ITERATION=  , I5  // )
      DO  20 J=1,11
      ID(J) = I1(IREP,J)
      ICASE(J) = I2(IREP,J)
      NA(J) = I3(IREP,J)
      IDSP(J) = I4(IREP,J)
      IDCP(J) = I5(IREP,J)
      IRLS(J) = I6(IREP,J)
C   2 READ ( 5,    3, END=11 ) ID(J), ICASE(J), NA(J), IDSP(J), IDCP(J),
C    1 IRLS(J)
    3 FORMAT ( I2,2I3, I12, I20, I10 )
C
C     WHERE   ID     = INPUT IDENTIFIER NUMBER
C             ICASE = CASE NUMBER
C             NA     = CITY NUMBER
C             IDSP  = NUMBER OF STOL PASSANGERS ( DAILY )
C             IDCP  = NUMBER OF CTOL PASSANGERS ( DAILY )
C             IRLS  = RUNWAY LENGTH OF STOL
C
C
C     CHECK INPUT DATA FROM ROUTE MODEL
C
      IF ( J - NA(J))  11,   4,  11
    4 IF (ID(J) - 13)   11,   5,  11
    5 IF (NA(J)-11 )   6,   6,  11
    6 IF (NA(J)) 11,  11,   7
    7 IF (ICASE(J)-6 )   8,   8,  11
    8 IF (ICASE(J)) 11,  11,   9
    9 IF (IRLS(J)) 11,  11,  10
   10 IF (IRLS(J)-1350 )  14,  15,  15
   11 WRITE ( 6,  12 ) NA(J), ID(J)
   12 FORMAT (29H ERROR IN INPUT DATA - CITY   , I2 /27H PROGRAM TERMINA
     1ED IN READ /37H PORTION OF TERMINAL MODEL INPUT ID = , I2 )
      GO TO 750
   14 RLS(J)= 1350.
      WRITE ( 6, 17 ) ID(J), ICASE(J), NA(J), IDSP(J),IDCP(J), IRLS(J)
      GO TO  20
   15 RLS(J)= IRLS(J)
      WRITE ( 6, 17 ) ID(J), ICASE(J), NA(J), IDSP(J),IDCP(J), IRLS(J)
   17 FORMAT (1H , I2, 2I3, I12, I20, I10 )
   20 CONTINUE
C
C     READ INPUT DATA FROM CONTROL MODEL
```

```
C
      DO  40 K=1,11
      ID2(K) = I10(IREP,K)
      NA2(K) = I11(IREP,K)
      IACT(K) = I12(IREP,K)
      IAST(K) = I13(IREP,K)
      IEACT(K) = I14(IREP,K)
      IEAST(K) = I15(IREP,K)
      LFCR(K) = I16(IREP,K)
      NSR(K) = I17(IREP,K)
C  21 READ ( 5,  22, END=  39 ) ID2(K), NA2(K),IACT(K),IAST(K),IEACT(K)
C    1IEAST(K), LFCR(K), NSR(K)
   22 FORMAT ( I2, I3, 5I10, I3 )
      WRITE ( 6, 23 ) ID2(K), NA2(K), IACT(K), IAST(K), IEACT(K),
     1 IEAST(K), LFCR(K), NSR(K)
   23 FORMAT ( 1H , I2, I3, 5I10, I3 )
C
C     WHERE ID2   = INPUT IDENTIFIER NUMBER
C           NA2   = CITY NUMBER
C           IACT  = BASIC CTOL AIRPORT LAND
C           IAST  = BASIC STOL AIRPORT LAND
C           IEACT = EXCESS CTOL AIRPORT LAND
C           IEAST = EXCESS STOL AIRPORT LAND
C           LFCR  = TOTAL LINEAR FEET OF CTOL RUNWAYS
C           NSR   = NUMBER OF STOL RUNWAYS
C
C     CHECK INPUT DATA FROM CONTROL MODEL
C
      IF ( ID2(K) - 23 )  39,  24,  39
   24 IF ( NA2(K)- 11 )  26,  26,  39
   26 IF ( NA2(K))39,  39,  28
   28 IF ( IACT(K)) 39,  30,  30
   30 IF ( IAST(K)) 39,  32,  32
   32 IF ( IEACT(K))  39,  34,  34
   34 IF ( IEAST(K))  39,  36,  36
   36 IF ( NSR(K))  39,  38,  38
   38 IF (K - NA2(K))  39,  40,  39
   39 WRITE ( 6, 12 ) NA(K), ID2(K)
      GO TO 750
   40 CONTINUE
C
C     ESTABLISH VALUES OF CONSTANTS USED IN THIS PROGRAM
C
      VA = 16.75
      AK1 = 2.399
      AK2 = 2.014
      AK3 = 13.972
      E = 2.718282
      CF = 43560.
      WRITE ( 6, 50  )
   50 FORMAT ( 1H1, 12H OUTPUT DATA  // )
C
C     INPUT DATA CHECKING COMPLETE - BEGIN CALCULATIONS
C
      DO 740 N = 1,11
C
C    ESTABLISH VALUES OF INPUT VARIABLES FOR EACH CITY
C
```

```
      POP = IPOP (N)
      A = IA (N)
      AL = SQRT (A)
      JCASE = ICASE (N)
      DSP = IDSP (N)
      DCP = IDCP (N)
      RD = IRLS (N)
      ACT = IACT (N)
      AST = IAST (N)
      EACT = IEACT (N)
      EAST = IEAST (N)
      ANSR = NSR (N)
      ALFCR = LFCR(N )
C
C     SELECT TYPE OF CALCULATIONS BASED ON CASE NUMBER
C     WHERE
C                             CTOL AIRPORTS   STOL AIRPORTS
C              CASE 1              1                0
C              CASE 2              2                0
C              CASE 3         1 (WITH STOL)         0
C              CASE 4         1 (WITH STOL)         1
C              CASE 5         1 (WITH STOL)         1
C                             1 (WITHOUT STOL)
C              CASE 6              0                1
C
      GO TO ( 100, 200, 300, 400, 500, 600 ) , JCASE
C
C     CASE 1 - CALCULATIONS
C
  100 TACP = DCP * 365.  +  DSP * 365.
      SPAC = 0.
      ANSR = 0.
      DO 120 NSCT = 1,2
  110 CALL TERCOS
      FCA(NSCT) = FCB
  120 CONTINUE
      IF ( FCA(1) - FCA(2) ) 125, 125, 127
  125 FCB = FCA(1)
      GO TO 129
  127 FCB = FCA(2)
  129 FC = 16. * FCB
      IGATS = 0
      TDCP = DCP + DSP
      IGATC =(0.156 * (( 0.675 * AL ) ** 0.5991 )) * 60.
      IGPTS = 0
      IGPTC = 17.5 + 0.018 * (SQRT(TDCP))+ 0.031*(TDCP ** 0.4 )
      ISTC = 0
      ICTC = FC
      GO TO 700
C
C     CASE 2 - CALCULATIONS
C
  200 TACP =(DCP / 2.) * 365. + (DSP / 2.) * 365.
      SPAC = 0.
      ANSR = 0.
      DO  220 NSCT = 1,2
      CALL TERCOS
      FCA(NSCT) = FCB
```

```
  220 CONTINUE
      IF ( FCA(1) - FCA(2)) 225, 225, 227
  225 FCB = FCA(1)
      GO TO 229
  227 FCB = FCA(2)
  229 CONTINUE
      FC =(2. * FCB) * 16.
      IGATS = 0
      IGATC =(0.156 * (( 0.5 * AL ) ** 0.5991 )) * 60.
      IGPTS = 0
      TDCP = ( DCP + DSP ) / 2.
      IGPTC = 17.5 + 0.018 * (SQRT(TDCP))+ 0.031*(TDCP ** 0.4 )
      ISTC = 0
      ICTC = FC
      GO TO 700
C
C     CASE 3 - CALCULATIONS
C
  300 TACP =  DCP * 365.
      SPAC = DSP
      ANSR = 0.
      DO 320 NSCT = 1,2
      CALL TERCOS
      FCA(NSCT) = FCB
  320 CONTINUE
      IF (FCA(1) - FCA(2)) 325, 325, 327
  325 FCB = FCA(1)
      GO TO 329
  327 FCB = FCA(2)
  329 CONTINUE
      FC = 16. * FCB
      IGATC =(0.156 * (( 0.675 * AL ) ** 0.5991 )) * 60.
      IGATS = IGATC
      TDCP = DCP + DSP
      IGPTC = 17.5 + 0.018 * (SQRT(TDCP))+ 0.031*(TDCP ** 0.4 )
      IGPTS = IGPTC
      ICTC = FC
      ISTC = 0
      GO TO  700
C
C     CASE 4 - CALCULATIONS
C
  400 X= -(AL / 2.)
  405 L = 0
  410 L = L + 1
      Q = AL / 4. - X / 2.
      WRITE ( 6, 412 ) X, L                                             CHECK 3
  412 FORMAT ( 4H X = , F8.2, 4H L = , I8 )                             CHECK 4
      AC = Q * AL
      DC = (0.375 * AL ) -(X / 4.)
      DEN =  0.7 * DSP / A
      SPAC = DEN * AC
      SPAS = DSP - SPAC
      DS =(((0.6875)  * (AL ** 2.) + (X * AL) + ( 1.25 * ( AL ** 2.)))
     1*((0.7 * DSP) / ( 2. * AL)) + (ABS (X) * 0.3 * DSP)) /  ( DSP +
     2 ( DEN * AL * Q ))
      STT = 0.156 * (   ABS(DS) ** 0.5991 )
      CTT = 0.156 * ( ABS (DC) ** 0.5991 )
```

7

```
      CA = VA * (( CTT * SPAC ) + ( STT * SPAS))
      CN =  300000. +(51.87 * SPAS)
      IF (ANSR - 1.) 422, 420, 422
  420 CT1 = ( SPAS * 49.) +(18586265. * RD / 1350.)
      CD1 = 0.04 * CT1
  422 CONTINUE
      CL =  (( 844. * (( POP / 1000.) ** 0.309)) +  A ** 0.971 )  /
     1(((10. * ABS(X)) ** 0.867) + 0.000000001  )
      CT2 =  ( SPAS * 63.) +(2343930. * RD / 1350. )
      CD2 = 0.04 * CT2
      AST1 = ((28. * SPAS) +((E ** 4.42686) * (SPAS ** 0.798))) /  CF
      IF ( AST1 - EAST ) 440, 440, 443
  440 AST2 = AST
      GO TO 450
  443 AST2 = AST + AST1 - EAST
      IF ( JCASE - 5)  444, 520, 444
  444 TACP = DCP * 365.
      DO 445 NSCT = 1,2
      CALL TERCOS
      FCA(NSCT) = FCB
  445 CONTINUE
      IF (FCA(1) - FCA(2)) 446, 446, 447
  446 FCB = FCA(1)
      GO TO 448
  447 FCB = FCA(2)
  448 CONTINUE
      FC = FCB * 16.
  450 IF (ANSR - 1.) 456, 452, 456
  452 TCT1 = (AK1 * CD1) + (AK2 * ( 1.1 * CT1 + 60. * CL )) + (AK3 *
     1 ( CN + CA )) + FC
  456 TCT2 = ( AK1 * CD2 ) +  AK2 *(1.1 * CT2 +  1.5 * AST2 * CL )  +
     1(AK3 * ( CN + CA )) + FC
      IF ( TCT2 - TCT1 ) 464, 464, 458
  458 IF ( TCT1 ) 464, 464, 460
  460 TCT3 = TCT1
      GO TO 468
  464 TCT3 = TCT2
  468 TCT(L) = TCT3
      FC1(L) = FC
      BL = L
  472 X = X + 1.
      IF ( BL - AL ) 410, 410, 476
  476 CONTINUE
      TCT4 = TCT(1)
      AM = 0.
      FC = FC1(1)
      DO  484  M=2,L
      IF (TCT4 - TCT(M)) 484, 484, 480
  480 TCT4 = TCT (M)
      FC = FC1(M)
      AM = M - 1
  484 CONTINUE
C
C     CALCULATION OF OUTPUT DATA
C
      X = -( AL / 2.) + AM
      Q = AL / 4. - X / 2.
      AC = Q * AL
```

```
      DC = ( 0.375 * AL ) - ( X / 4. )
      DEN = 0.7 * DSP / A
      SPAC = DEN * AC
      SPAS = DSP - SPAC
      DS =  (( 0.6875 * ( AL ** 2. ) + ( X * AL ) + ( 1.25 * ( AL ** 2.
     1 )) * (( 0.7 * DSP) / ( 2. * AL)) + ( ABS(X) * 0.3 * DSP )) / (
     2 DSP + ( DEN * AL * Q ))
      IGATS =(0.156 * ( ABS(DS) ** 0.5991 )) * 60.
      IGATC =(0.156 *(((DC * SPAC  +  0.675 * AL * DCP ) / ( DCP + SPAC
     1 ) ** 0.5991 )) * 60.
      IGPTS = 17.5 + 0.018 * (SQRT(SPAS))+ 0.031 * (SPAS ** 0.4)
      TDCP = DCP + SPAC
      IGPTC = 17.5 + 0.018 * (SQRT(TDCP))+ 0.031 * (TDCP ** 0.4)
      ICTC = FC
      ISTC = TCT4 - FC
      GO TO 700
C
C     CASE 5 - CALCULATIONS
C
C     CASE 5 FOR STOL IS THE SAME AS CASE 4
C     EXCEPT FOR CTOL TERMINAL COST -
C
  500 GO TO 400
C
C     CALCULATIONS FOR CTOL TERMINAL COST
C
  520 TACP = (DCP / 2.) * 365.
C
C     CALCULATIONS FOR CTOL TERMINAL WITH STOL RUNWAYS
C
      DO 540 NSCT = 1,2
      CALL TERCOS
      FCA(NSCT) = FCB
  540 CONTINUE
      IF (FCA(1) - FCA(2)) 550, 550, 560
  550 FCC = FCA(1)
      GO TO 570
  560 FCC = FCA(2)
  570 CONTINUE
C
C     CALCULATIONS FOR CTOL TERMINAL WITHOUT STOL RUNWAY
C
      SPAC = 0.
      ANSR = 0.
      DO 580 NSCT = 1,2
      CALL TERCOS
      FCA(NSCT) = FCB
  580 CONTINUE
      IF (FCA(1) - FCA(2)) 590, 590, 595
  590 FCD = FCA(1)
      GO TO 596
  595 FCD = FCA(2)
C
C     ADD COSTS FOR THE CTOL TERMINALS AND RETURN TO CASE 4
C
  596 FC = (FCC + FCD) * 16.
      ANSR = NSR (N)
      GO TO 450
```

```
C
C     CASE 6 - CALCULATIONS
C
  600 P = DSP + DCP
      CT2 = (63. * P ) + ( 2343930. * RD / 1350. )
      CD2 = 0.04 * CT2
      DS = 0.675 * AL
      CA = VA * ( 0.156 * ( ABS(DS)**0.5991) * P )
      CN = 300000. + ( 51.87 * P )
      CL = ( 844. * (( POP / 1000. ) ** 0.309 ) * ( A ** 0.971 )) /
     1(( 5. * AL ) ** 0.867 )
      E = 2.71828
      AST1 = (( 28. * P ) + (( E ** 4.42686 ) * ( P ** 0.798 ))) / CF
      IF (AST1 - EAST ) 620, 620, 625
  620 AST2 = AST
      GO TO 630
  625 AST2 = AST + AST1 - EAST

  630 TCT2 = (AK1 * CD2) +  AK2 * (1.1 * CT2 + 1.5 * AST2 * CL ) +
     1 AK3 * (CN + CA)
      TCT4 = TCT2
C
C     CALCULATION OF OUTPUT DATA
C
      IGATC = 0
      IGATS =(0.156 * (( 0.5 * AL ) ** 0.5991 )) * 60.
      IGPTC = 0
      IGPTS = 17.5 + 0.018 * (SQRT( P ))+ 0.031 * ( P ** 0.4)
      ICTC = 0
      ISTC = TCT4
      GO TO 700
C
C     DATA OUTPUT SECTION
C
  700 IDNO = 34
      WRITE ( 6, 701 ) IDNO, IGATS, IGPTS, IGATC, IGPTC, N,IREP
      WRITE ( 7, 702 ) IDNO, IGATS, IGPTS, IGATC, IGPTC, N, IREP
  701 FORMAT ( 1H , I2, I4, 4I5, 49X, I5 )
  702 FORMAT ( I2, I4, 4I5 , 49X, I5 )
C
C     WHERE IDNO  = IDENTIFIER NUMBER (34)
C           IGATS = GROUND ACCESS TIME TO STOL ( MIN )
C           IGPTS = GROUND PROCESS TIME AT STOL ( MIN )
C           IGATC = GROUND ACCESS TIME TO CTOL ( MIN )
C           IGPTC = GROUND PROCESS TIME AT CTOL ( MIN )
C           N     = CITY NUMBER
C
  740 CONTINUE
  750 STOP
      END
```

```
      SUBROUTINE TERCOS
C
C     THIS SUBROUTINE COMPUTES THE CTOL COST FOR THE CTOL - STOL
C     EFFECTIVENESS AND COST MODELS
C
      COMMON TACP, SPAC, ANSR, POP, AL, ALFCR, ACT, EACT, NSCT, FCB, A
C
C     CONVERT VARIABLES IN COMMON FOR USE IN SUBROUTINE TERCOS
C
      IFLAG = NSCT
      TAP = TACP
      P = POP
      RUNL = ALFCR
      TSP = SPAC
      TOA = ACT
      NO = ANSR
      ELAND = EACT
      AR = A
C
C     WHERE
C     IFLAG IS NUMBER OF STORIES IN TERMINAL BUILDING
C     TAP IS TOTAL ANNUAL PASSENGERS USING CTOL TERMINAL. MAY
```

```
C       INCLUDE STOL PASSENGERS
C       P IS 1985  URBAN AREA  POPULATION
C       RUNL  IS TOTAL RUNWAY LENGTHS FROM  CONTROL  GROUP  IN FEET
C       TSP   IS TOTAL DAILY  STOL  PASSENGERS
C       TOA   IS TOTAL  AREA  FROM CONTROL  GROUP  IN SQ FT
C       NO   IS  NUMBER OF  STOL  RUNWAYS
C       AL  IS  LENGTH OF  SIDE  OF THE CITY IN MILES
C       ELAND  IS THE  EXCESS LAND  PROVIDED BY  CONTROL  GROUP  IN SQ FT
C
C
C       CALCULATE  LAND VALUE IN  1969  DOLLARS  PER SQUARE  FOOT
C       R IS  THE  DISTANCE  FROM CBD  TO THE  CTOL
C
        R =  AL/2.
        PRICE =((844. *(P/10000.)**.309*AR**.971)/(10.0*R)**.867)/1.87
        PRICE =  PRICE/43560.0
C
C       CHANGE NUMBER OF STOL  RUNWAYS  TO FLOATING PT
C
        FN = NO
C
C       CALCULATE TYPICAL PEAK HOUR  PASSENGERS
C
        IF (TAP.GE.20000000.0)  TPHP = TAP*.03
        IF (TAP.GE.10000000.0.AND.TAP.LT.20000000.0)  TPHP=TAP*.035
        IF (TAP.GE.1000000.0.AND.TAP.LT.10000000.0)   TPHP=TAP*.040
        IF (TAP.GE.500000.0.AND.TAP.LT.1000000.0)     TPHP=TAP*.050
        IF (TAP.GE.100000.0.AND.TAP.LT.500000.0)      TPHP=TAP*.065
        IF (TAP.LT.100000.0)  TPHP=TAP*.120
C
C       CALCULATE   COSTS FOR  BUILDINGS AND RUNWAYS
C
C       PARKING
C
        CPARK =  26.72 *TPHP
C
C       TERMINAL
C
        CTERM =  940.5 * TPHP
C
C       RUNWAY PAVING
C
        CRUN =  .484 * ( RUNL* 200.0 +  RUNL * 75.0+1800000.0*TPHP/8000.)
C
C       COST OF  STOL  RUNWAYS IF NEEDED
C
        CSTOL=(FN*1500000.*(.04*2.399 +1.1*2.014)+(200000.+430.*TSP/16.)
      1*13.972 ) / 16.
C
C       NOW  LOOK AT  LAND COSTS
C       LAND FOR  PARKING  LOT  IN SQ FT
C
        AR1 =  1.3 * 280.0 * TPHP
C
C       LAND  FOR TERMINAL  BUILDING IN SQ FT
C
        FLAG = IFLAG
        AR2  =(180.0/ FLAG)* TPHP
```

```
C
C     LAND FOR STOL RUNWAY IF NEEDED
C
      AR3  =FN * 2000.0 * 200.0
C
C     COMPARE LAND NEEDED TO LAND AVAILABLE
C
      AE = .75 * ELAND
      AB = AR1 +AR2 + AR3
      DIF = 0.0
      IF(AB.GE.AE) DIF = AB - AE
      TTOA = TOA + DIF
C
C     CALCULATE LAND COST
C
      FLCOS = TTOA * PRICE * .10
C
C     CALCULATE TOTAL COST
C
      TCOST = CPARK + CTERM + CRUN + CSTOL + FLCOS
C
C     CONVERT TOTAL COST TO VARIABLE USED IN THE MAIN PROGRAM
C
      FCB = TCOST
      RETURN
      END
```

APPENDIX 4-E

Computer Printout

Cost Version of The CTOL and STOL Terminals

```
C
C     DATA OUTPUT SECTION - COST VERSION
C
C     ACCUMULATE TOTAL COST FOR ALL AIRPORTS IN ALL CITIES
C
  700 TLCST = ICTC + ISTC + TLCST
  740 CONTINUE
      IDNO = 78
      WRITE ( 6, 745 ) IDNO, TLCST, IREP
      WRITE ( 7, 746 ) IDNO, TLCST, IREP
  745 FORMAT ( 1H , I2, F20.0, 53X, I5 )
  746 FORMAT ( I2, F20.0 , 53X, I5 )
C
C     WHERE IDNO  = IDENTIFIER NUMBER
C           TLCST = TOTAL COST OF ALL CTOL AND STOL TERMINALS
C
  749 CONTINUE
  750 STOP
      END
```

APPENDIX 4-F

Parametric Terminal Cost Analysis

List of Symbols and Assumed Values

Symbol	Definition	Assumed Value
A	area	
A/C	aircraft	
α	angle of sector	
BAG	number of bags/type passenger	
C_{AC}	total annual cost of A/C apron	
C_{BAG}	total annual cost of Baggage System	
C_d	total annual cost of double track	
C_p	total annual cost of Parking Structure	
C_{pl}	total annual cost of Parking Lots	
C_{RD}	total annual cost of Internal roads and ramps	
C_{rds}	total annual cost of roads	
C_t	total annual cost of terminal building	
C_{tun}	total annual cost of Subterranean Stations	
CA	construction cost of aircraft parking/ft^2	\$5/ft^2
CDT	construction cost of double track	\$1,288/ft
CLB	construction cost of conveyor/ft	
CPL	constructions cost of parking lot/ft^2	\$2/ft^2
CPS	constructions cost of parking structure/ft^2	\$6.50/ft^2
CRD	construction cost of Roads (1) bituminous concrete (2) Portland Cement concrete	\$138.4 $.10^3$/Lane-Mi \$1.037 $.10^6$/Lane-Mi
CRFmi	Capital Reduction factor = $\dfrac{i(i+1)^m}{(i+i)^m-1}$	

Symbol	Definition	Assumed Value
	where m (first two digits) = expected life time years (20,15) i (last two digits) = interest rate (10)	
CRP	construction cost of Ramp/ft^2	\$10,73/ft^2
CSORT	construction cost of sorter of capacity Q	
CST	construction cost of subterranean station/ft^2	
CTL	construction cost of terminal building/ft^2	\$6.27/ft^2
CTUN	construction cost of tunnel/ft length-ft dia.	\$25.58/ft-ft.
DT	diameter of Tunnel (ft)	
ELV	ft elevation (average)	
f	fraction of loading area on ground level	0.5
FL	number of floors	
FLT	number of flight storage areas	3
g	number of sorting decisions for type sorter	2,3
GSF	geometrical shape factor	
j	maximum number of sorting levels were flow rate can be kept at maximum rate of Q	
LAN	number of lanes	
LB	length of conveyor belt [complete (ft)]	
LRD	length of road/lane	
LS	length of station	200 ft.
LT	length of tunnel	
N	total number of sorters in system	
n	number of sorting levels	
n	number of stations	6
OA	annual operating cost of aircraft apron	\$.75/ft^2 \$0.75/ft^2
ODT	annual operating cost of double track	\$.75/ft \$0.75/ft
OLB	annual operating cost of conveyor system/ft	
OPL	annual operating cost of parking lot	\$.50/ft^2 \$0.50/ft^2

Symbol	Definition	Assumed Value
OPS	annual operating cost of parking structure/ft^2	\$.50/ft^2 \$0.50/ft^2
ORD	annual operating cost of roads	
ORP	annual operating cost of ramp/ft length-ft deviation	
OST	annual operating cost of subterranean Station	
OTL	annual operating cost of terminal building/ft^2	\$1/ft^2
OTUN	annual operating cost of tunnel/ft length-ft. dia.	\$1 ft-ft dia.
PAX	typical peak hour passengers expected for a particular airport	
PIC	number of baggage collection points	
PL	price of land (dollars per acre)	
PR	packing ratio	
Q	sorter capacity	
RMP	(ft of ramp/lane) (LAN)	
WS	width of station	185 ft.
Z	fraction of PAX using Rubber Wheel transportation	0.98 for national average

4-F-1 General Cost Model

Parking Lots:

$$C_{pl} = \frac{PAX(1.3)280}{3600}\left[CPL(CRF2010) + OPL + \frac{PL(.10)}{4.356 \times 10^4}\right].$$

Where:
TPHP = 3600
1.3 car spaces/TPHP
280 ft^2/car space
4.356×10^4 ft^2/acre
.10 = CRF for land at 10% interest (20 year life).

Parking Structures:

$$C_p = PAX(1.3)(280)\,[CPS(CRF1510) + OPS].$$

Where there are
TPHP = 3600
1.3 car spaces/TPHP
280 ft^2/car space

Roads:

$$C_{rds} = \frac{PAX(Z)}{3600}\,(LRD(LAN)(CRD(CRF2010) + ORD) +$$

$$RMP(ELV)[CRP(CRF2010) + ORP)].$$

Terminal Building (except baggage handling system):

$$C_t = \frac{PAX(319.6)}{3600}\left[CTL(CRF2010) + OTL + \frac{PL(1.2)}{FL(4.356 \times 10^4)}\right].$$

Where
TPHP = 3600
319.6 ft^2/TPHP
1.2 implies 20% extra land for roads, etc.
4.356×10^4 ft^2/ACRE

Cut and Cover tunnel cost (for open apron only)

$$C_{tun} = (LT)(DT)\,[C_{tun}(CRF2010) + OTUN].$$

Double track in tunnel (open apron):

$$C_d = \left(\frac{PAX}{3600}\right)\left(\frac{LT}{2}\right)[CDT\ (CRF2010) + ODT]$$

3600 TPHP/terminal unit

2 = since only double track costs are known a single track cost is approximated by using double track for 1/2 the tunnel length.

Subterranean Station (open apron; less tracks):

$$C_{sts} = \left(\frac{PAX}{3600}\right) [(LS)(WS)6][CST(CRF2010) + OST]$$

3600 TPHP/terminal
6 gate positions or stations/terminal.

A/C Apron Cost (less packing and terminal area; includes geometrical shape factor and equipment and service vehicle areas:

$$C_{AC} = \frac{PAX(60,000)}{(200)(3600)} (PR)(GSF)[CA(CRF2010) + OA + \frac{PL(1.1)}{4.356 \times 10^4}]$$

where there are
$60,000 \ ft^2$/A/C parking area ($200 \times 300 \ ft^2$ each)
200 TPHP/A/C
3600 TPHP/terminal
1.1 = 10% excess land for A/C access to apron area from taxi ways.

Terminal Road Cost and Ramp Cost:

$$C_{RD} = \left(\frac{PAX}{3600}\right)\left(\frac{3600}{60}\right) [.40(.52)(2)(20)] + 0.4(1.5)(20)$$

$$+ (0.22)(5)(40)[\frac{(12)[CRD(CRF2010) + ORD](f)}{5280}$$

$$+ (1-f)(12)(CRP)(CRF2010) + ORP]$$

where the numbers as written mean:

$\left(\frac{PAX}{3600}\right)$ = number of terminal units

$\left(\frac{3600}{60}\right)$ = arrival rate of TPHP (60 TPHP/min.)

.40 of TPHP come by car and unload at terminal

.52 of TPHP comes by car

2 minutes to unload/car

20 ft unloading room/car

.4 of TPHP come by Taxi

1.5 minutes to unload/Taxi

20 ft unloading Rm/Taxi

.22 of TPHP come by bus

5 min. unloading time/bus

40 ft/bus

12 ft/roadlane (STANDARD)

5280 ft/mile

4-F-2 Baggage System Cost

Let: Q = given sorter capacity (Bags/hr)

$q = 2$ for a "yes-no" sorter

3 for a "Right-Left-Straight" sorter

Bag = 1.5 bags/Domestic passenger

= 2.5 bags/international passenger

Pic = number of bag pick-up points = $\frac{(PAX)(BAG)}{(3600)(Q)}$

n = number of sorting levels

j = maximum number of levels where flow rate can be kept at maximum rate Q

N = total number of sorters

FLT = number of storage areas for flights.

Now a simple tree diagram yields:

$$FLT = g^n$$

or $n = \log_g(FLT)$

likewise

$$j = \log_g(Pic) \text{ or } g^j = Pic$$

number of sorters for maximum load on system is given by

$$N = \left(\frac{Pic}{g}\right)(g') + \left(\frac{Pic}{g^2}\right)(g^2) + \ldots + \left(\frac{Pic}{g^j}\right)g^j + g^{j+1} + g^{j+2} + \ldots g^n$$

or

$$N = j(Pic) + \sum_{K=j+1}^{n} g^K = j(Pic) + g^j \sum_{K=1}^{n-j} g^K$$

$$= \text{Pic}\ [j + \sum_{K=1}^{n-j} g^K] = \text{Pic}\ [\log_g(\text{Pic}) + \sum_{K=1}^{\log_g(\frac{FLT}{Pic})} g^K]$$

$$N = \frac{(PAX)(BAG)}{(3600)(Q)}\ [\log_g(\frac{(PAX)(BAG)}{(3600)(Q)}) + \sum_{K=1}^{\log_g(\frac{FLT(3600)(Q)}{(PAX)(BAG)})} g^K\ ]$$

Now we can write the cost of the Baggage System as

$$C_{BAG} = N(CSORT)CRF1510) + (LB)(1.4)(CLB)(CRF1510) + OLB$$

where 1.4 40% addition belt is needed.

4-F-3 TERMINAL CONFIGURATIONS

4-F-3.1 Satellite Sector (See Figure 4.12)

Assume $x = r_7$ and $y = 0$ for $R >> r_7$

Therefore $\alpha = 2 \tan^{-1} (\frac{r_7}{r_5})$

$$r_5 = \frac{A_1}{X} = \frac{A_1}{r_7}$$

where A_1 = Central nub terminal area and parking area and excess area and road area

$$= \frac{\alpha}{2} r_3^2 = 878,087 \text{ ft}^2$$

bounds on r_7:

(1) for open apron style parking

r_7 max = 589 + 100 + 300 = 989'

(2) for nose-in parking style

r_7 min = 206 + 300 + 300 = 806'

(3) If we let $A_2 = \frac{1}{2}$ waiting room and $\frac{1}{2}$ public space

= 145, 193 ft^2/floor on 2 floors

Then r_7 = 215 + 300 + 300 = 815' = Value to be used
where r_6 = 215 ft.

Satellite terminal

radius = r_6 = 215

A_2 = 145, 193 ft^2/floor 2 floors

Roof Parking = 145, 193 ft^2 520 spaces

<u>Central terminal area</u> = Total = Satellite Term/Area (Total)

= 1,143,400 - 2(145, 193) = 426, 507 ft^2/floor 2 floors

Roof Parking = 426, 507 ft^2 1,525 spaces

<u>Total Parking Necessary</u> at 1.3 spaces/TPHP 280 ft^2/space

4,675 spaces 1,130,400 ft^2 TOTAL

Central Parking on three levels = $1,310,400 - \left[\frac{426,507 + 145,193}{3}\right]$

$= \frac{638,700}{3} = 212,900\ ft^2$/level 3 Three Levels.

<u>Road area and Excess Land</u> = 20% of terminal area (TOTAL)

= 228,680 ft^2

of 4675 parking spaces = 50 to 55% are for passenger and visitors. The remainder are for employees, etc.

Total area of Central Complex = A_1

= 228,680 Road & Excess
212,900 Parking
<u>426,507</u> Central Terminal
878,087 ft^2 = A_1

$R = r_5 + r_7$

Sector area = $(\frac{\alpha}{2})R^2 \cdot r_5 = r_7 r_5 = A_1 + E \frac{\pi(r_7)^2}{2}$

Let E = Service Vehicle area for 8 vehicles/AC 300 ft^2/vehicle =

14,400 ft^2 r_5 = 2,537 ft.

and

$\alpha = 2 \text{ arc tan } (\frac{815}{2537}) = .622 \text{ rad} = \underline{35.6° = \alpha}$

r_3 = 1,680 ft.

as a check

$$r_3 + r_7 \leq r_5$$

$1680 + 815 = 2495 < 2537$ We have a feasible solution by adjusting E we can obtain.

$$R = 3352 \text{ ft.}$$

$$GPR = \frac{A_1 + E + \pi(r_7)^2}{(\frac{\alpha}{2})\ R^2}$$

$$PR = \frac{\pi[(r_7)^2] - 50(r_7 - r_6)}{360{,}000}$$

4-F-3.2 Finger Terminal Unit

According to the areas noted previously the approximate dimensions are shown on Figures 4.13 and 4.14.

Unit I may have its parking area in place in area #1 or #2.

Unit II is a modification of I where I has only two floors II has 2 floors for the finger section and three for the main terminal.

I	II
GSF = 1	GSF = 1
PR = 1.87	PR = 1.56
f = 0.5	f = 0.5

4-F-3.3 Open Apron Unit (See Figure 4.15)

Dimensions were determined from previously determined areas. The min. 1000 ft A/C terminal separation was based on a 3 minute transit time to the A/C at 15 mph.

(a) Car configuration (See Figure 4.17)

1. capacity: 15 people standing plus operator.
2. velocity: 15 mph horizontal, with minimal accelerations and decellerations

3. coded for particular flight: color, numbers
4. load time: less than one minute
5. load rate 2 cars/flight and 6 flight: 1 car/30 sec.
6. electric rail

(b) Subterranean Station Gate (See Figure 4.16)

1. center platform 200 ft x 185 ft.
2. max. of 4 A/C loading escalators
3. max. of 3 baggage loading conveyors
4. dual service by electric car
5. comfortable waiting room and small concessions area.

GSF = 1

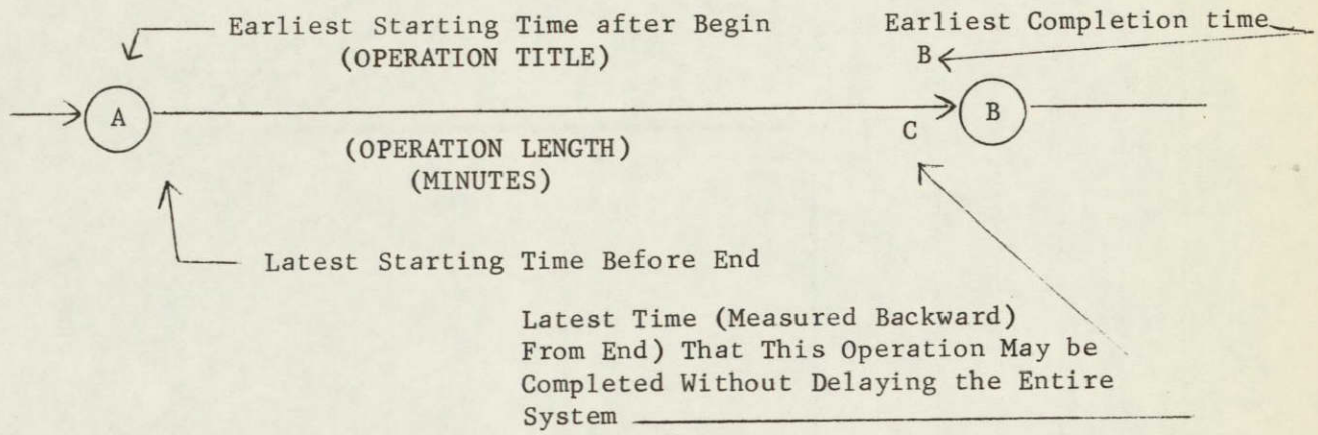
PR = 4.19

f = 1.5

APPENDIX 4-G

4-G-1 Critical Path Analysis for Terminal Subsystem Improvement Priorities

The following figures show the CPM plots used to determine the priorities for subsystem improvement listed in section 4.5.2. The following key will be helpful in reading the figures.



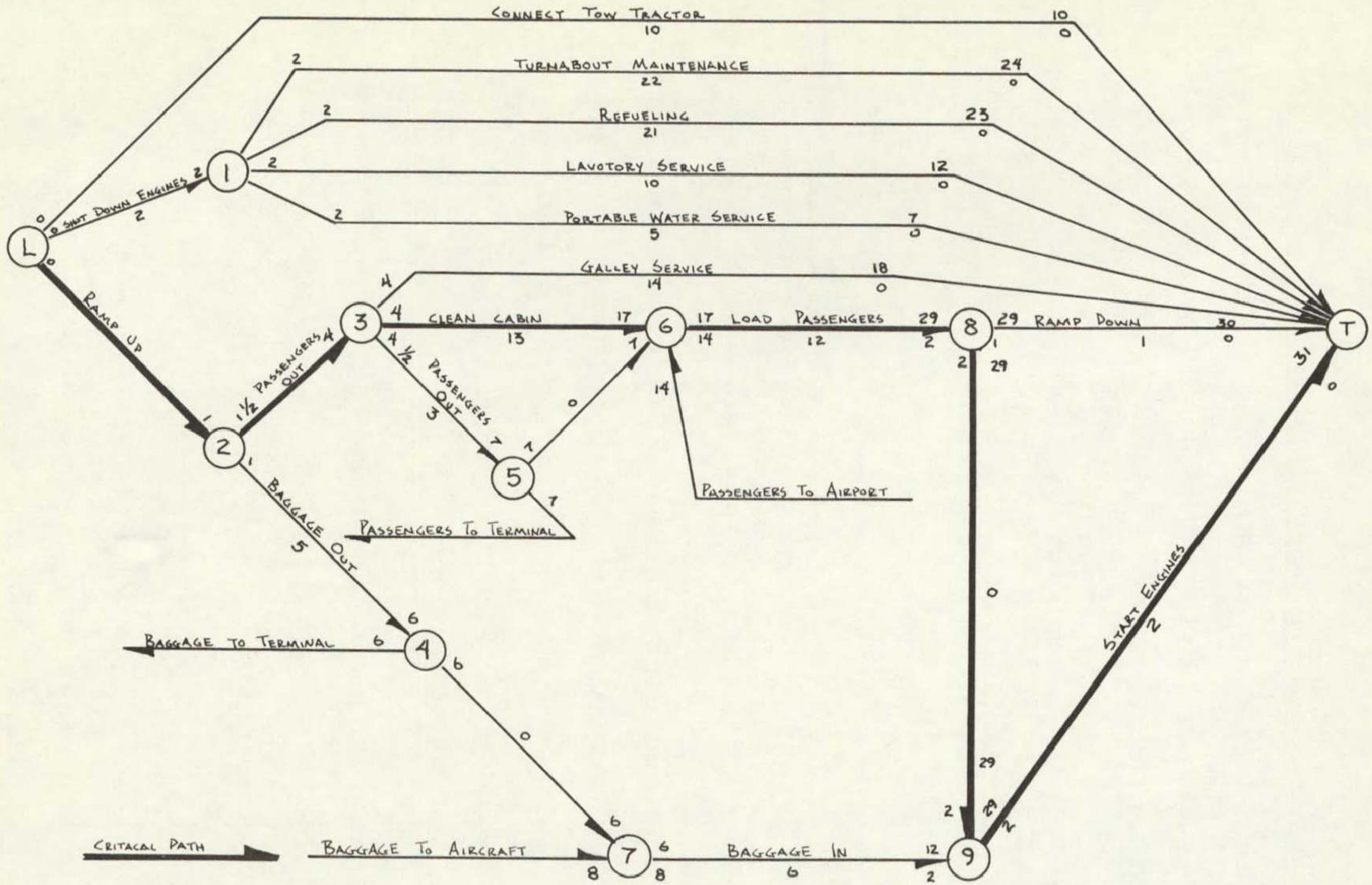
Arrowhead indicates that all operations after B are dependent on this operation. This operation is dependent on all operations terminating at A.

A bold line indicates that this operation is on the critical path.

From figures 4-G-1 and 4-G-2, the following terminal requirements for the L-1011-385 aircraft are established.

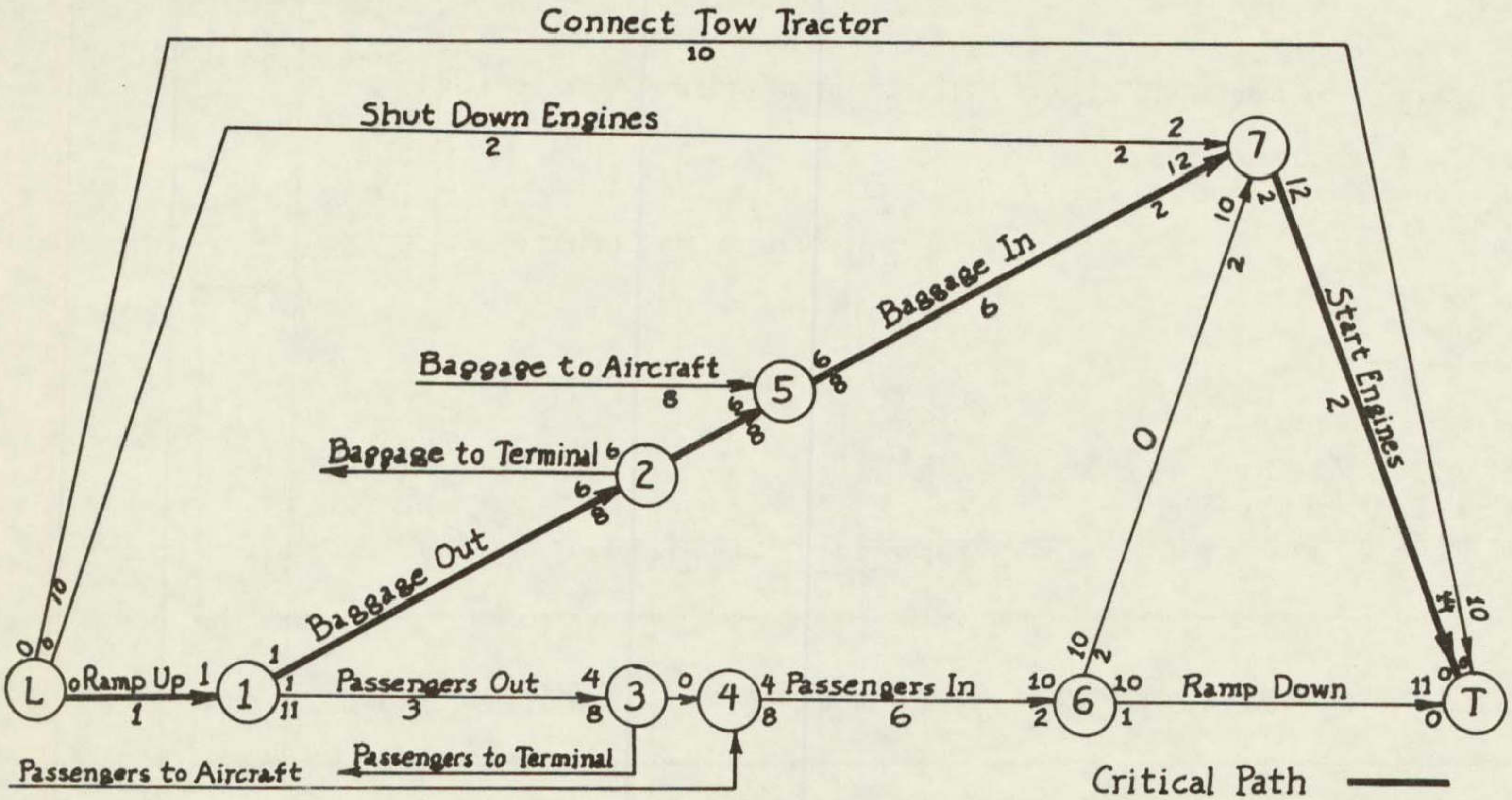
Turnaround Station: Passengers must be ready to load at least 14 minutes prior to roll out. Baggage must be ready to load at least 8 minutes prior to roll out. Passengers are deplaned at best 7 minutes after roll in.

Intermediate Station: Passengers must be ready to load at least 8 minutes prior to roll out. Baggage must be ready to load at least 8 minutes prior to roll out. Passengers are deplaned at best 4 minutes after roll in. Baggage is unloaded at best 6 minutes after roll in.



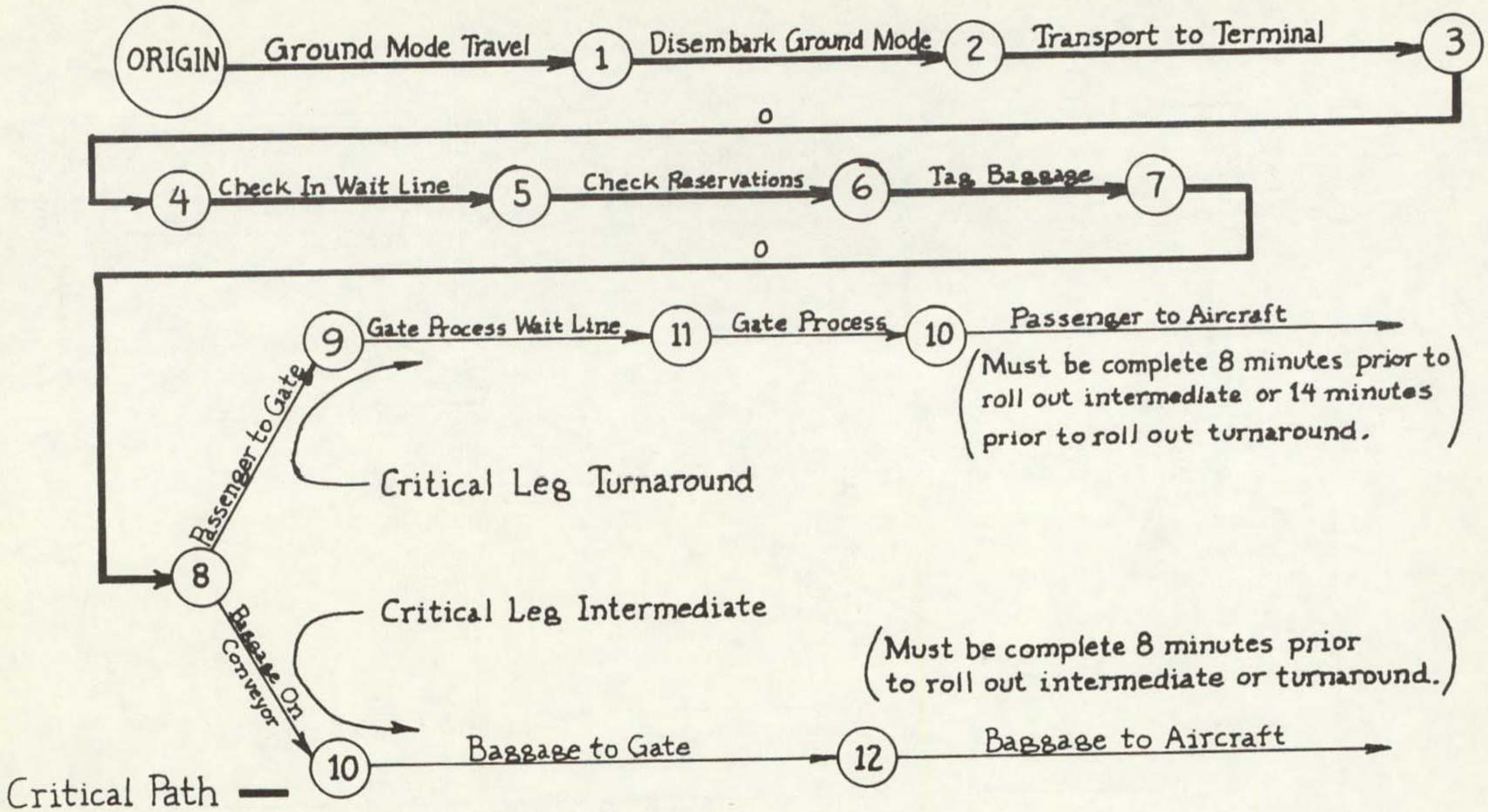
L-1011-385 Turnaround Station (CPM)

Figure 4-G-1



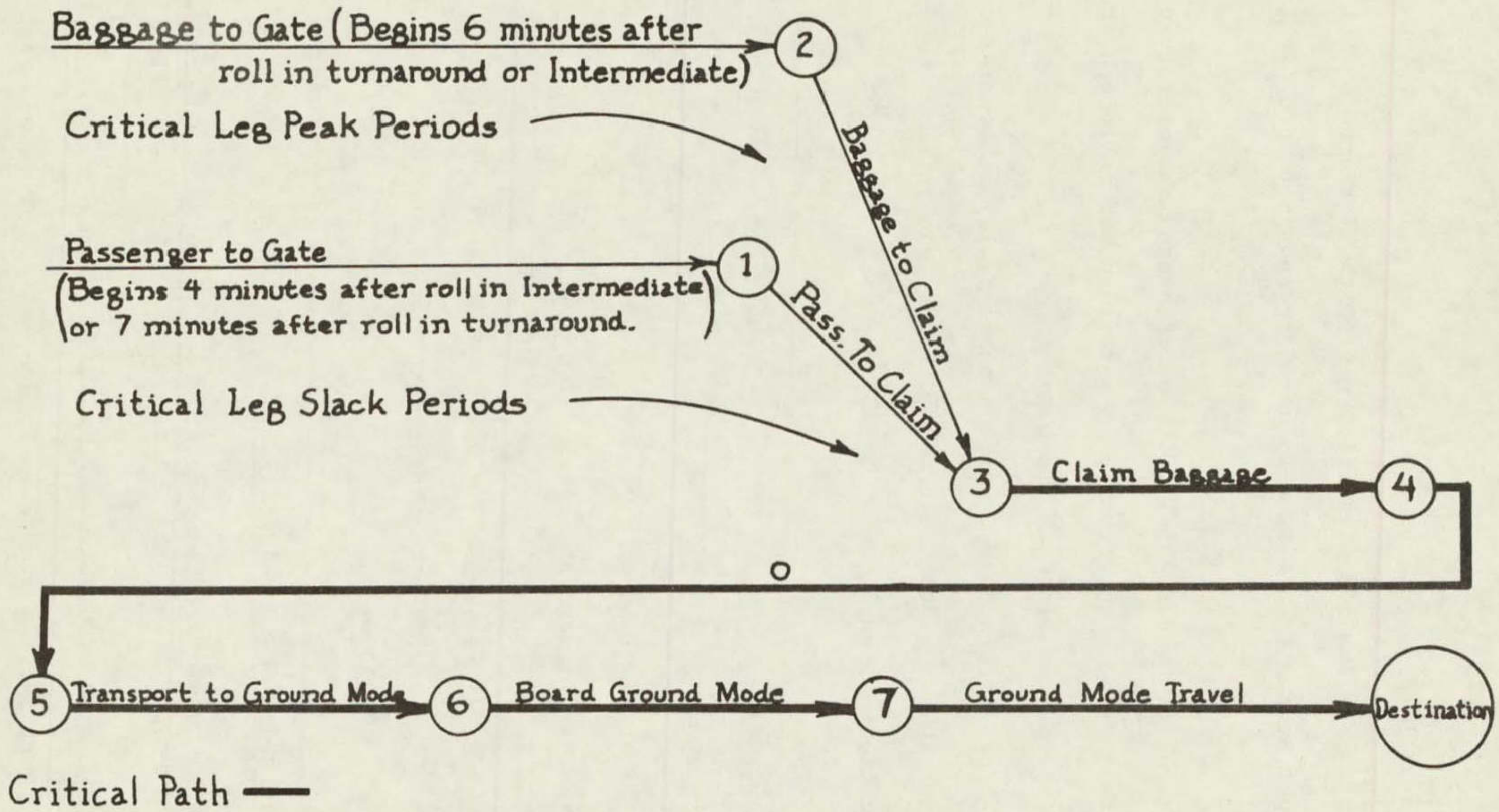
L-1011-385 Intermediate Stop (CPM)

Figure 4-G-2



Departing Passenger Terminal Process (CPM)

Figure 4-G-3



Arriving Passenger Terminal Process (CPM)

Figure 4-G-4

4-G-2 Preliminary Design of Baggage Handling System

Assumptions:

1. Each gate will serve four pads.
2. Maximum gate utilization will allow six flights (twelve operations) per pad per hour. (Pad flight volume corresponds to one terminal module.)
3. An average of sixty passengers will be exchanged per operation.
4. Passengers may check three bags, no more than 34" in length, but average passenger will check 2.5 bags.
5. Conveyors for arriving and departing baggage will be separate.

The following points in the system require individual analysis.

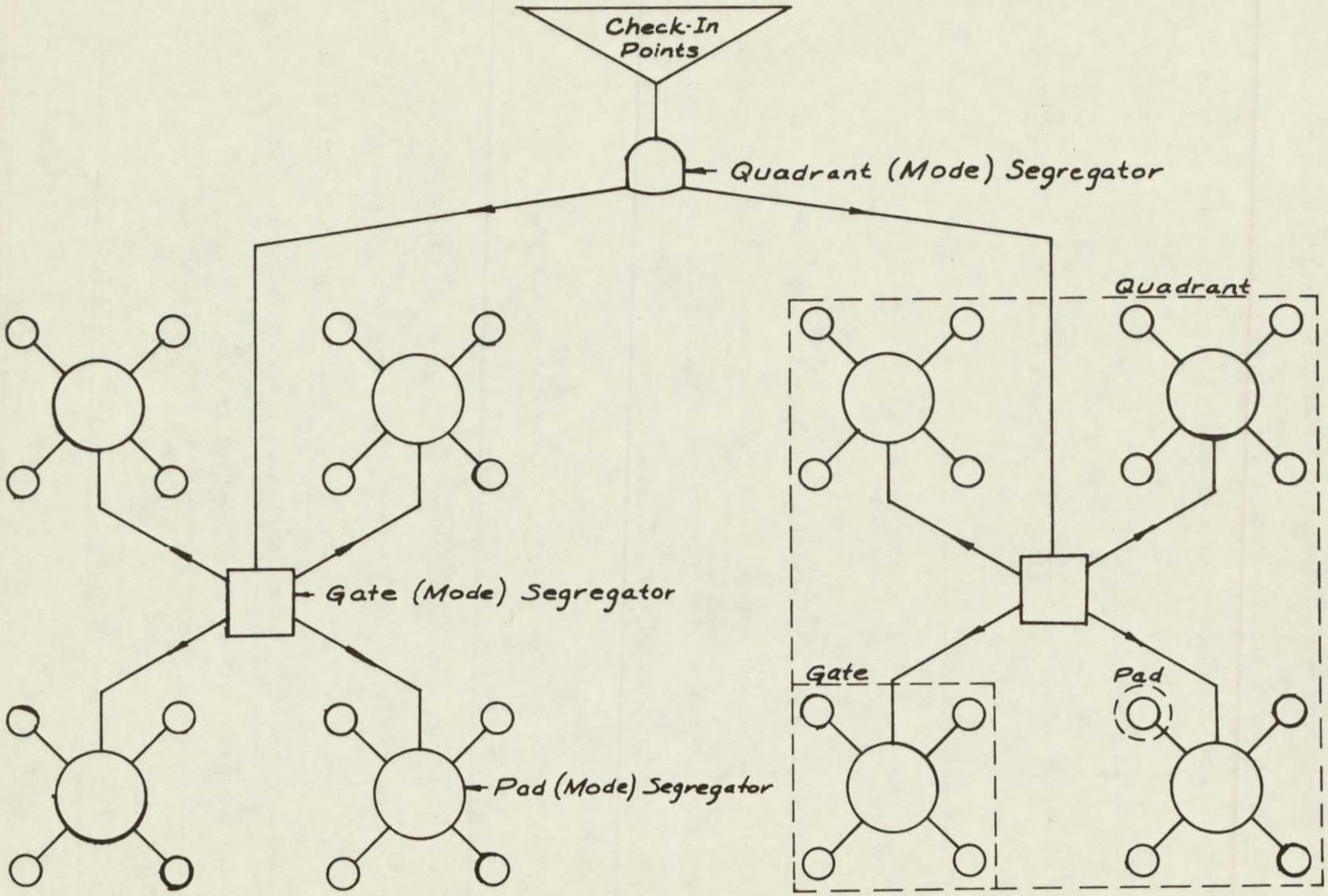
1. Identification system.
2. Code readers.
3. Segregators.
4. Pad storage system.
5. Aircraft loading/unloading system.
6. Private vehicle luggage storage and retrival.

The New York terminal is thought to place the greatest demand on the system. Therefore, in "Loading" the system upstream of the pads, demands for the New York terminal will be used.

Quadrant Requirements for New York Terminal:

$$\left(372\ \frac{\text{operations}}{\text{hr}}\right)\left(1/2\ \frac{\text{vehicle}}{\text{operation}}\right)\left(1/6\ \frac{\text{pad hr}}{\text{vehicle}}\right)\left(1/4\ \frac{\text{gate}}{\text{pad}}\right)\left(1/4\ \frac{\text{quadrant}}{\text{gate}}\right) = 1.94$$

Two quadrants will be required. The New York terminal baggage distribution system could be schematically drawn as in Figure 4-G-5. It is apparent that the subsystems of this schematic (quadrants, gates, pads) could easily form the entire system for smaller terminals. Also, the system can be easily expanded.



New York Schematic

Figure 4-G-5

More pads could be served by a single gate, more than four gates could form a quadrant, mode segregators could preceed the quadrant segregators and so on. Certain physical restraints quickly impose themselves on any ambitious expansion plan however. This will become obvious in the following analysis.

Required Capacity for Pad Segregator:

$$(4 \text{ pads})\ (6 \text{ flights/pad-hr})\ (60\ \frac{\text{passengers}}{\text{flight}})\ (2.5\ \frac{\text{bags}}{\text{passenger}}) = 3600\ \frac{\text{bags}}{\text{hr.}}$$

Required Capacity for Gate Segregator:

$$(4 \text{ gates})\ (3600\ \frac{\text{bags}}{\text{gate-hr}}) = 14,400 \text{ bags/hr}$$

At this point it seems advantageous to divide the input between two quadrant segregators rather than imposing design requirements of 28,800 bags per hour on a single segregator. The required capacities of the gate and pad segregators will not be changed. The altered portion of the schematic appears in Figure 4-G-6.

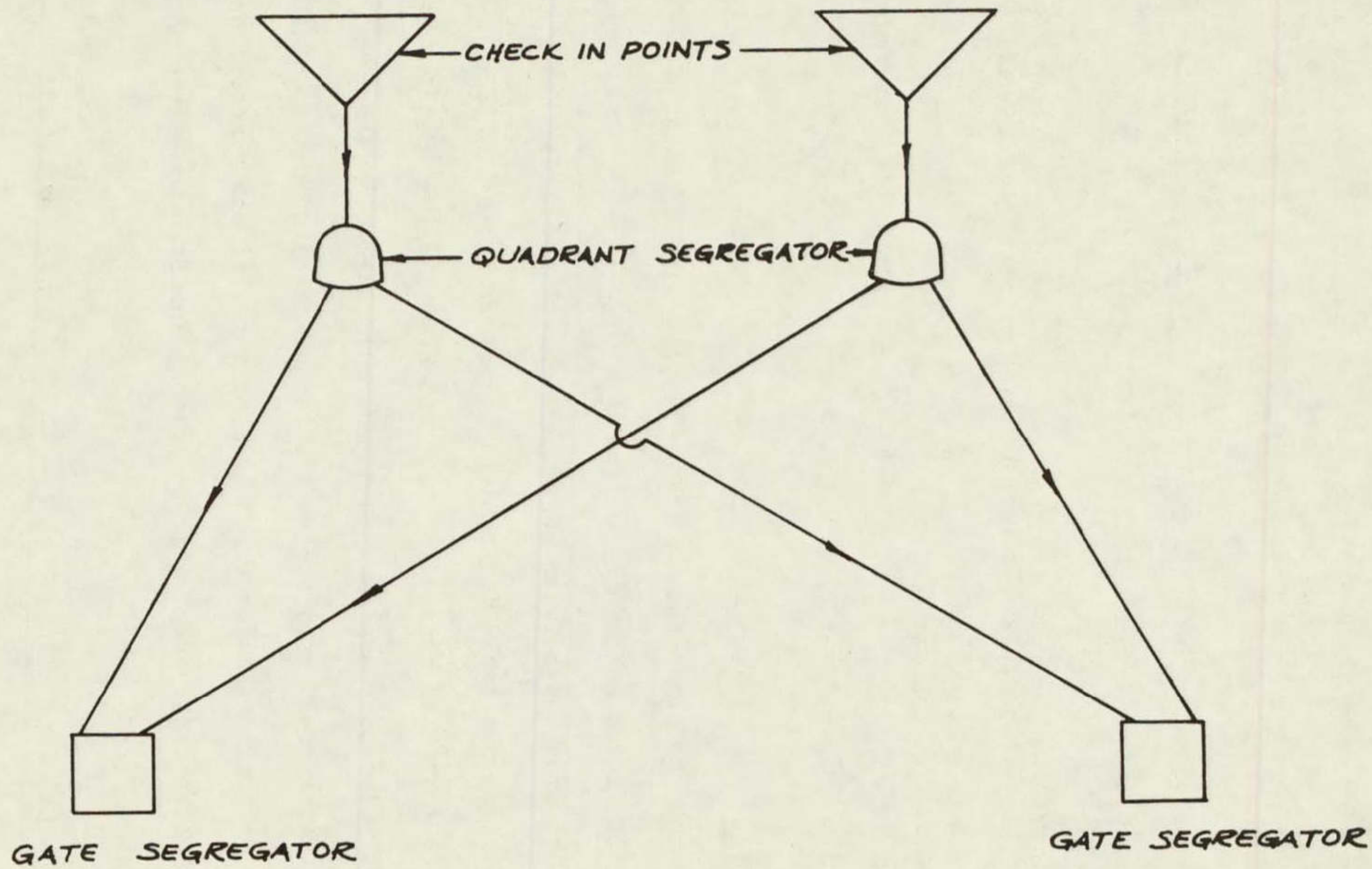
Now we must design a baggage segregator capable of sorting 14,400 bags per hour. This will also impose steep requirements on the code readers. In order to make this burden somewhat lighter, and also to facilitate handling random sized luggage, we shall use "totes" which carry three bags each (all of one passenger's luggage). The totes will be three feet square and will have display windows for inserting cosed identification/routing cards. Six inch gaps will be maintained between totes to facilitate sorting.

Identification Design:

Alpha-numerics: Destination; Flight Number

Optic or Magnetic Binary:

INFORMATION	QUADRANT	GATE	PAD	FLIGHT	SOCIAL SECURITY NO.	GROUND MODE AT DESTINCTION
Number of 10 row columns required	1	1	1	3	9	1



New York Revision

Figure 4-G-6

Sixteen columns will be necessary. Allow one inch on each end of the tote wide, with one inch between columns.

Code Reader Requirements:

Belt Velocity = $(14,400 \frac{\text{bags}}{\text{hr.}})\ [(1/2.5)\frac{\text{totes}}{\text{bag}})]\ (3.5 \frac{\text{ft}}{\text{tote}})\ (\frac{1 \text{ hour}}{3600 \text{ sec}}) = 5.6$ ft/sec

Scanner Reading Time = $(1/12 \text{ ft})\ (1/5.6 \frac{\text{sec}}{\text{ft}}) = 0.01488$ Seconds

This requirement makes photo-cells impractical, magnetic coding will be required. Code readers will require ten magnetic pick-ups and relays or solid state switching circuits. Code readers at the parking luggage storage facility will also require an amplifier.

Segregator Design:

Let us assume that each tote and it's luggage will weigh 75 pounds. The belt speed is 5.6 ft/sec and the totes are separated by six inches. Also, some clearance must be provided between conveyors - design a three inch space between conveyors. The time available for a simple transfer device to accelerate a tote, displace it 3.25 feet, and return to clear the next tote is $(3.5 \text{ ft})\ (\frac{1}{5.6 \text{ ft/sec}})$ = 0.625 seconds. The accelerations required would damage the luggage.

If the actuator moved with the belt a longer transfer time would be possible. Assuming this condition and also that the actuctor will exert a ten pound force on the tote until its transverse velocity reaches one ft/second, the merge length and time may be computed:

Acceleration a = $(10 \text{ lbs})\ (32.2 \frac{\text{ft}}{\text{sec}^2})\ (\frac{1}{75 \text{ pounds}}) = 4.3 \text{ ft/sec}^2$

time to 1 ft/sec velocity ta = $\frac{1 \text{ ft/sec}}{4.3 \text{ ft/sec}^2} = 0.23$ seconds

transverse distance moved in ta = $(0.5)\ (4.3 \text{ ft/sec}^2)\ (0.23 \text{ sec})^2 = 0.11$ ft

time to move remaining 3.14 ft = $t_v = \frac{3.4 \text{ ft}}{1 \text{ ft/sec}} = 3.14$ seconds

Total Merge Time: tm = (3.14 + 0.23) sec = 3.37 seconds

Total Merge Length : lm = (3.37 sec) (5.6 ft/sec) + 3 ft = 21.9 ft

These accelerations, velocities, merge lengths, and merge times are not unreasonable. Figure 4-G-7 shows a transfer mechanism consisting of chains oriented along the desired tote path which have retractable pins attached to them. On a "divert" signal from the code reader, the pins are lowered behind the tote and it is pushed onto the branch conveyor.

Each transfer mechanism will require:

(24) (4) = 96 ft of chain, 14 pin holders and pins, a drive, two pin deflectors, a pin actuator and eight sprockets (cost $1200).

Pad Storage - Flight Segregator:

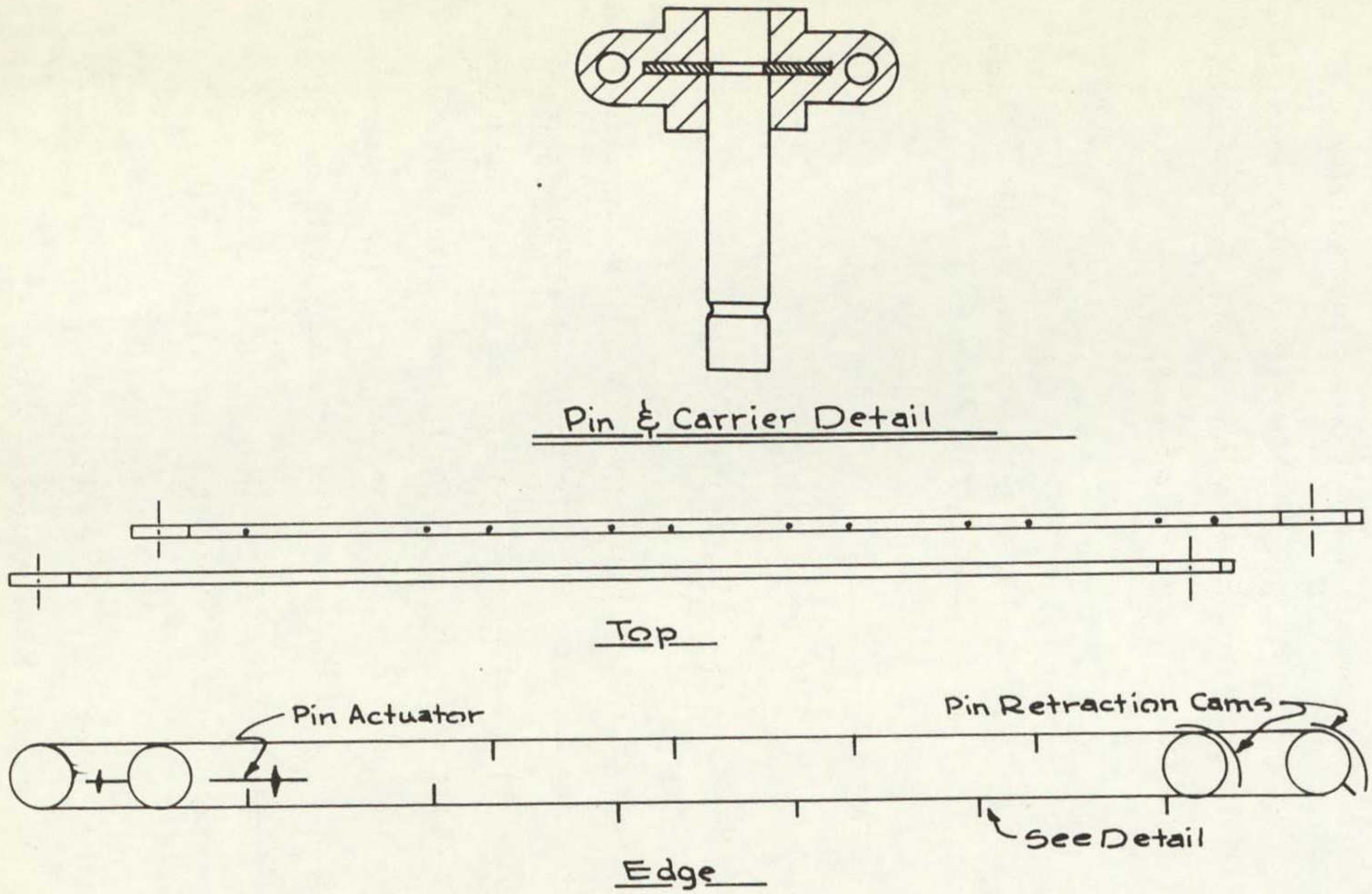
The pad will handle:

$$(6 \text{ flights/hr}) \left(\frac{60 \text{ passengers}}{\text{flight}}\right) \left(1 \frac{\text{tote}}{\text{passenger}}\right) = 360 \text{ totes/hr}$$

We will convey the luggage from the pad segregator to the pad on a gravity conveyor. This will allow accumulation and will provide steady flow to the flight segregator. Tilt tables will be sufficiently fast for this operation. Figure 4-G-8 shows the flight segregator in schematic form. Tilt tables are sections of gravity conveyor which have the capability of tilting on demand by rotating about an axis parallel to the normal line of travel. This dumps the totes onto the flight accumulation conveyors.

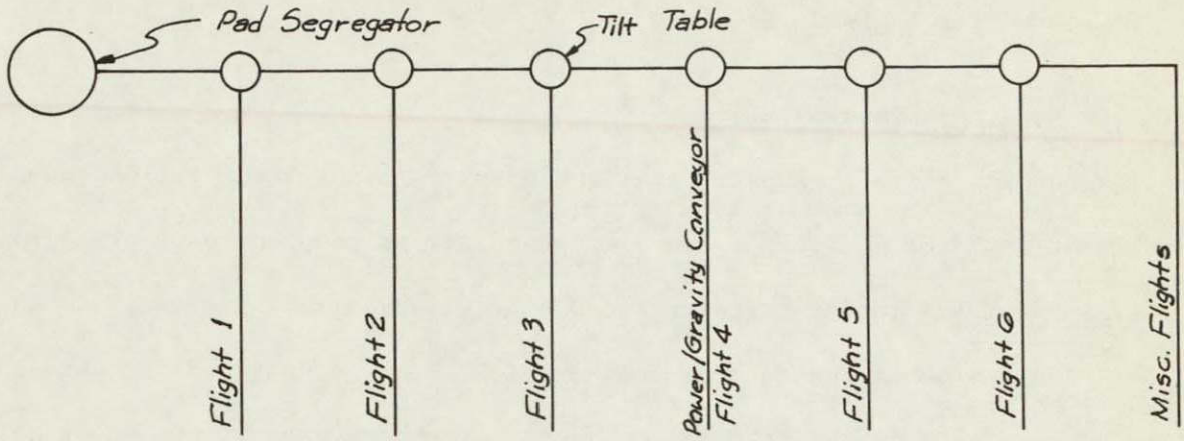
Each pad storage system will require six tilt tables and code readers. Also

[(1 accumulator) + (6 flights)](60 totes/flight)(3 ft/tote) = 1260 feet of gravity accumulating conveyors will be needed (cost $8000).



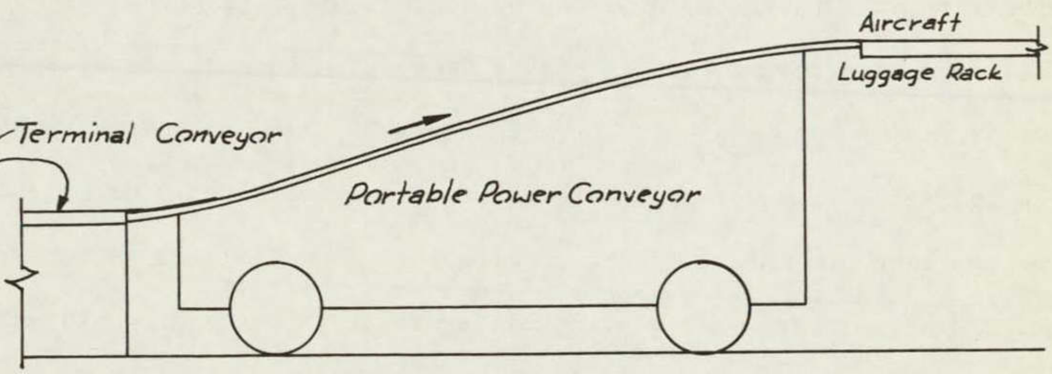
TRANSFER MECHANISM

Figure 4-G-7



FLIGHT SEGREGATOR

Figure 4-G-8



LOADING AIRCRAFT

Figure 4-G-9

The extra accumulator will accept bags for all flights which are not yet scheduled for a given pad.

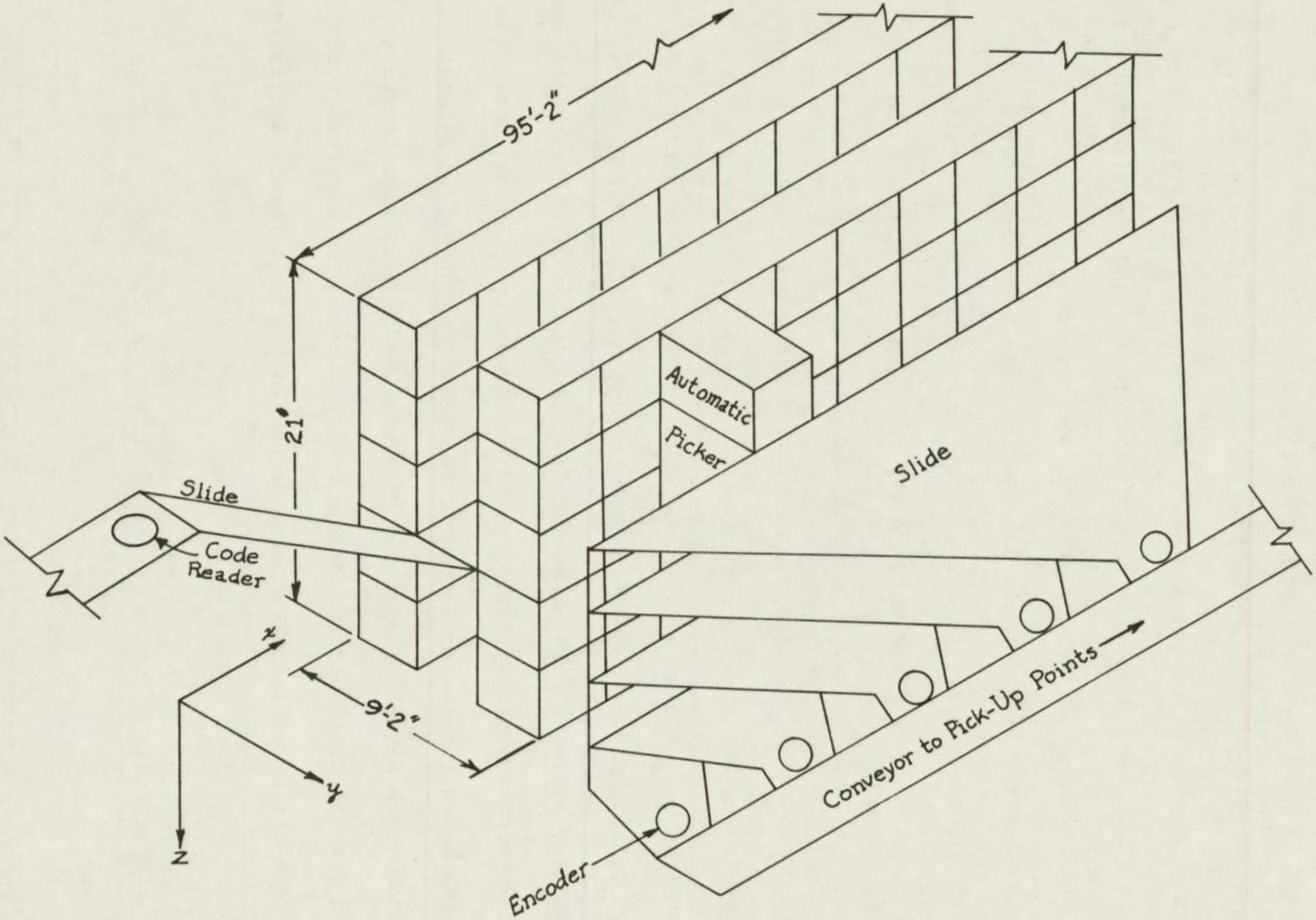
Aircraft Loading/Unloading System:

By running a traction belt under the gravity flight accumulation conveyors, it would be possible to have them operate as powered conveyors also. A gravity conveyor inside the aircraft would deliver arriving baggage to the system. This assumes that one or two men pick the bags destined for this stop and load them on the exiting conveyor. If the baggage racks in the aircraft are actually free roller conveyors it would be possible to mate the terminal conveyor to the baggage rack and use terminal power to load the baggage bay. This is shown in Figure 4-G-9. It must be pointed out that terminals exchange totes in this system, making standardization mandatory. The only additions to the system required in this process are the portable power and gravity conveyors, estimated at $2000 and $400 each.

4-G-2.1 Private Vehicle Luggage Storage and Retrevial:

The size of this system will depend on that other ground modes enter the terminal. We have therefore, designed a "module" with a 300 tote capacity.

A portion of the module is shown in Figure 4-G-10. Allowing two inches between cells for framework and an additional foot vertically to provide for cell access, the dimensions of the module be as shown. Totes would arrive from the ground mode sorters on a gravity conveyor. This conveyor would mate with an extendible slide section which is in turn matched with a series of thirty tilt tables. The thirty tables have the ability to move as a unit vertically. Proximity switches on the tilt table unit would sense if a cell were full or empty. As totes passed the code reader at the top of the slide, the social security number would be read and fed to the computer. When the tote moved in front of an empty cell the tilt table would rotate, depositing the tote in the cell and



Parker Luggage Module

Figure 4-G-10

at the same time notifying the computer of the cell's coordinates. When all sensors indicated full cells, the elevating device would lower or raise the tilt table unit, making another layer of cells accessible.

Coordinate notification would work as follows. The elevating mechanism would produce a signal corresponding the "z" coordinate, the activation of a particular tilt table would provide the "x" coordinate, and the direction of rotation of the table would indicate the "y" coordinate.

When a passenger called for his baggage the computer would search its matrix for the coordinates of the correct cell and signal the automatic picker to eject that tote onto a slide which would carry it to a coding machine. Here the baggage pick-up number from which the passenger signaled for his luggage would be coded on the tote and the tote would proceed through a sorting system to the pick-up point. Since pick-up and check-in points are at the same location, the tote will remain at this point to be used by a departing passenger.

The tilt table unit will be operated by a single shaft coupled to the tables by electromagnetic clutches. Thus the module will require 30 gravity conveyor tilt tables, 30 electromagnetic clutches, three actuating motor and the tilt table elevating mechanism. Also a reader, ten coding machines, an automatic picker, an extendible slide conveyor and framework would cost approximately \$20,000. The cost of sorting system which would accompany this unit depends entirely on terminal layout. \$4000 per pick-up station is a reasonable estimate.

Power Requirements:

A very safe estimate of the power requirements of the system could be made as follows:

$$\left(60\ \frac{\text{passengers}}{\text{operation}}\right)\left(\frac{75\ \text{lbs}}{\text{passenger}}\right)(5.6\ \text{ft/sec})\left(\frac{1\ \text{HP sec}}{550\ \text{ft-lbs}}\right)\left(.7457\ \frac{\text{KW}}{\text{HP}}\right) =$$

34.17 KW/Peak Hr. Operation

Cost Model Derivation:

PHO = Peak Hour Operations

PPC = Public parking capacity - cars

CIP = Number of Check in Points

CL = Total conveyor length, feet

Crf = Capital recovery factor, 10% interest - 20 years

Quadrant Segregators - \$6000 ea.

$$(\$6000)\left(\frac{\text{operations}}{\text{hr.}}\right)\left(1/2\ \frac{\text{vehicle}}{\text{operation}}\right)\left(6\ \frac{\text{Pad Hr}}{\text{Vehicles}}\right)\left(1/4\ \frac{\text{gate}}{\text{pad}}\right)\left(1/4\ \frac{\text{quad}}{\text{gate}}\right)$$

$$\left(\frac{1\ \text{seg}}{\text{quad}}\right) = \text{PHO}\ (\$31.25)$$

Gate Segregators - \$6000 ea.

Pad Segregator - \$6000 ea.

$$(\$6000)\left(\frac{\text{operation}}{\text{hr.}}\right)\left(1/2\ \frac{\text{vehicle}}{\text{operation}}\right)\left(1/6\ \frac{\text{pad hr}}{\text{vehicle}}\right)\left(1/4\ \frac{\text{unit}}{\text{pad}}\right) = \text{PHO}\ (\$125.00)$$

Pad Storage System, Flight Segregator, Mobile Loading/Unloading Units - \$10400 ea.

$$(\$10{,}400)\left(\frac{\text{operations}}{\text{hr}}\right)\left(1/2\ \frac{\text{vehicle}}{\text{operations}}\right)\left(1/6\ \frac{\text{pad hr}}{\text{vehicle}}\right)\left(\frac{1\text{unit}}{\text{pad}}\right) = (\$866.67)\ \text{PHO}$$

Ground Conveyance Luggage Segregator - \$6000 ea.

exactly as many as quadrant segregators PHO (\$31.25)

Totes - \$5 ea.

$$(\$5)\left(\frac{\text{operations}}{\text{hr}}\right)\left(60\ \frac{\text{passenger}}{\text{operation}}\right)\left(\frac{1\ \text{tote}}{\text{passenger}}\right) = (\$300)\ \text{PHO}$$

Conveyor - \$30/ft

CL (\$30)

Pick-Up-Check-In-Points - \$4000 ea.

(\$400) CIP

Parker Luggage Storage Module - \$20,000 ea.

(estimated 30% of cars have luggage in storage) $(\$20{,}000)\ \frac{(PPC)\ (0.3)}{300} = (\$20)\ PPC$

Capital Recovery:

$Crf\ \{PHO[(3)\ (31.25) + 125 + 866.67 + 300] + (30)CL + (4000)\ CIP + (20)PPC\}$

$= (0.11746)\ [(1385.42)\ PHO + (30)\ CL + (4000)\ CIP + (20)\ PPC]$

$CR = (162.73)\ PHO + (3.52)\ CL + (469.84)\ CIP + (2.35)\ PPC$

Power - \$0.025/KW-HR

$(PHO)\ (34.17\ \frac{KW}{PHO})\ (\frac{\$.025}{KWHR})\ (\frac{8760\ Hr}{yr})\ (\$7483.23)\ PHO$

Maintenance Personnel \$2.50/hr

$(\frac{\$2.50}{hr\text{-}man})\ (\frac{PHO}{100}\ men)\ (\frac{8760\ hr}{yr}) = (\$219)\ PHO$

Total Annual Cost:

$TAC = (7864.96)PHO + (3.52)CL + (469.84)CIP + (2.35)PPC$

APPENDIX 5-A

AIRCRAFT DESIGN MODEL

5-A-1 Nomenclature

PAX	-----	Number of passengers
V	-----	Design cruise velocity - mph
V_{fps}	-----	Design cruise velocity - fps
RANGE	-----	Design range - miles
FL	-----	Fuselage length - feet
FD	-----	Fuselage outer diameter - feet
H	-----	Design cruise altitute - feet
T_h	-----	Temperature at cruise altitude - R
ρ_h	-----	Density of air at altitude - slugs/ft^3
μ_h	-----	Viscosity at altitude - slugs/ft-sec
ν_h	-----	Kinematic viscosity at altitude - ft^2/sec
Rey_{fus}	-----	Fuselage Reynolds No. at altitude
Rey_{wing}	-----	Wing Reynolds No. at altitude
C_{D_o}	-----	Parasite drag coefficient
C_{D_i}	-----	Induced drag coefficient
C_D	-----	Total drag coefficient
C_L	-----	Total lift coefficient
L/D	-----	Lift to Drag ratio
WG1	-----	First gross weight approximation - lbs
Thrust	-----	Total available cruise thrust - lbs
W(i)	-----	Weight of the "i"th component (See component weights formulae)

SFC	-----	Specific fuel consumption - lbs fuel/HP-sec
K	-----	Horsepower correction factor
CONST	-----	STOL Constant - 6.375
D	-----	Propeller diameter - ft.
HP_{sl}	-----	Total engine horsepower at sea level - HP
η_t	-----	Transmission efficiency factor - 0.90
η_p	-----	Propeller efficiency factor - 0.875
WG2	-----	Second gross weight approximation - lbs
$\triangle$WG	-----	WF1-WG2
WGF	-----	Final value of gross weight - lbs
OPW	-----	Operating Weight - lbs
WG_{empt}	-----	Weight empty - lbs
$V_{lift-off}$	-----	Lift off velocity - (118.5 fps)
NRP_{sl}	-----	Normal rated sea level power - HP
$Rey_{fus_{sl}}$	-----	Fuselage Reynolds No. at sea level
$Rey_{wing_{sl}}$	-----	Wing Reynolds No. at sea level
$C_{D_{o_{sl}}}$	-----	Sea level parasite drag coefficient
$Thrust_{roll}$	-----	Total available take off thrust - lbs
$Drag_{roll}$	-----	Total take off drag
a_{roll}	-----	Take off acceleration - ft/sec^2
g	-----	Gravity constant - 32.17 ft/sec^2
μ	-----	Ground roll friction - 0.2
RWL	-----	Runway length - ft
$Thrust_{sl}$	-----	Available sea level thrust of one engine - lbs
AR	-----	Aspect ratio - assumed 7.0
S	-----	Wing area - sq. ft.

App. 5-A-2 Design Model Formulae

A. Given input: PAX, V, RANGE.

B. Determination of fuselage length, FL; fuselage diameter, FD; and number of passengers abreast:

PAX	FL	FD	No. Abreast	
40	64.0	8.8	4	one aisle
60	77.7	10.5	5	
80	80.0	12.2	6	
100	92.1	12.2	6	
120	98.5	15.3	7	two aisles
140	104.2	15.3	7	
160	112.7	15.3	7	

C. Determination of cruise altitude, H:

V (mph)	H(ft)
200	20,000
300	25,000
400	30,000

D. Determination of cruise air conditions:

$$T_h = 547 - 0.003566\ H$$

$$\rho_h = \{0.00226\ (1-0.00000687\ H)\}^{4.2561}$$

$$\mu_h = 3.73\text{x}10^{-7}\ \{T_h/520\}^{1.5}\ \{718.7/(T_h+198.7)\}$$

$$\nu_h = \mu_h/\rho_h$$

E. Drag Calculations:

$$V_{fps} = V(88/60)$$

$$Rey_{fus} = (V_{fps}\cdot FL)/\nu_h$$

$$Rey_{wing} = (V_{fps}\cdot \sqrt{S/AR})/\nu_h$$

$$C_{D_o} = 1.21\ \{0.03/(Rey_{fus})^{1/7}\cdot[4(FL/FD)+6(FD/FL)^{1/2}+28(FD/FL)^2]$$

$$\cdot\ (\pi FD^2)/(4S) + (1.6\cdot 0.0744)/(Rey_{wing})^{1/7}\}$$

$C_L = (C_{D_o} \pi \cdot 0.87\ AR)^{1/2}$

If $C_L > 0.5$ then $C_L = 0.5$

$C_{D_i} = C_L^{\ 2}/(\pi 0.87\ AR)$

$C_D = C_{D_o} + C_{D_i}$

F. First Thrust and Gross Weight Calculations:

$L/D = C_L/C_D$

$WG1 = 1/2 \cdot C_L \cdot \rho_h \cdot S \cdot (V_{fps})^2$

Thrust = WG1/(L/D)

G. Component Weights Breakdown

$W(fuselage) = W(1) = 0.8\{FL^{1.5}\ FD^{0.25}\ (4.5\ WG1)^{0.15}\}$

$W(wing) = W(2) = \{0.15 - (0.063\ WG1)/100{,}000\}\ WG1$

$W(tail) = W(3) = 0.035\ WG1$

$W(landing\ gear) = W(4) = 0.04\ WG1$

$W(oil) = W(5) = 140$

$W(furnishings) = W(6) = 550 + 40 \cdot PAX$

$W(air\ condition) = W(7) = 500 + 13 \cdot PAX$

$W(hydralics) = W(8) = 0.0005(WG1)^{1.28}$

$W(electronics) = W(9) = 642$

$W(elect.equip) = W(10) = 1.61(WG1)^{0.55}$

$W(controls) = W(11) = 0.02 \cdot WG1$

$W(payload) = W(12) = 200(PAX + 3)$

$W(fuel) = W(13) = WG1\{1 - e^{-(RANGE+200+.75V)(SFC)/(1/(L/D))}\}$

where SFC is the specific fuel consumption = 0.55
This amount of fuel includes the standard FAA reserve fuel; enough fuel to fly to destination plus 200 miles plus enough fuel for 45 minutes cruising time at cruise speed.

$W(\text{fuel tanks}) = W(14) = 0.045 \cdot W(13)$

$$W(\text{engines and nacelles}) = W(15) = 1.5\{(\text{Thrust} \cdot V_{fps})/(K \cdot CONST \cdot 325)\}$$

$$W(\text{Propellers}) = W(16) = 56.8\{(D/10)^{.25}(.9HP_{sl})^{1/2} \cdot \pi D^2 \cdot 0.00205\}^{0.67}$$

where $D = 0.2\{(S \cdot AR)^{1/2} - FD\}$

and $HP_{sl} = (\text{Thrust} \cdot V_{fps})/(K \cdot 550\eta_t + \eta_p)$

where $\eta_t = 0.90$ and $\eta_p = 0.875$

$$W(\text{transmission}) = W(17) = 60\{(0.666\ HP_{sl} \cdot D)/50\}^{0.8}$$

$W(\text{misc.}) = W(18) = 0.05 \cdot WG1$

H. Second Gross Weight and other weights:

$$WG2 = \sum_{i=1}^{18} W(i)$$

$\Delta WG = WG1 - WG2$

At this point, assume that the iteraction is complete;

i.e., that $WGL \simeq WG2 = WGF$

$OPW = WGF - W(13) - W(12)$

$WG_{empt} = OPW - (2/3)\ W(15) - W(16) - W(17)$

I. Runway length Calculations:

For purposes of runway length calculations the lift off velocity is assumed to be a fixed constant.

$$V_{lift\text{-}off} = 118.5 \text{ fps}$$

$NRP_{sl} = 1.11\ HP_{sl}$

$Rey_{fus_{sl}} = (693{,}000 \cdot FL)$

$Rey_{wing_{sl}} = (693{,}000 \cdot \sqrt{S/AR})$

$$C_{D_{o_{sl}}} = 1.21\{0.03/(Rey_{fus_{sl}})^{1/7} \cdot [4(FL/FD)+6(FD/FL)^{1/2}$$

$$+ 28(FD/FL)^2] \cdot \pi(FD^2)/(4S) + (1.6 \cdot 0.0744)/(Rey_{wing_{sl}})^{1/7}$$

$$Thrust_{roll} = (1.2 \cdot NRP_{sl} \cdot \eta_p \cdot \eta_t \cdot 550)/(.7 \cdot V_{lift\text{-}off})$$

$$= (Thrust \cdot V_{fps})/(62.2 \cdot K)$$

$$Drag_{roll} = (1/2)\ \rho_{sl}(0.7 \cdot V_{lift\text{-}off})^2\ C_{D_{o_{sl}}} \cdot S$$

$$= 7.78 \cdot C_{D_{o_{sl}}} \cdot S$$

$$a_{roll} = g\{(Thrust_{roll} - Drag_{roll})/WGF - \mu\}$$

where $g = 32.17\ ft/sec^2$

$\mu = 0.2$

If $a_{roll} > 10\ fps^2$ then $a_{roll} = 10\ fps^2$

RWL = Distance to wheels off plus distance to climb 50 feet

Distance to climb 50 feet $\simeq$ one half the distance to wheels off

RWL = 1.5 {Distance to wheels off}

$RWL = 1.5\ (V^2_{lift\text{-}off})/(2 \cdot a_{roll})$

$Thrust_{sl}$(of one engine) $= (2.5 \cdot NRP_{sl})/4$

5-A-3 Aircraft Parametric Design Model Computer Flow Chart For STOL Aircraft

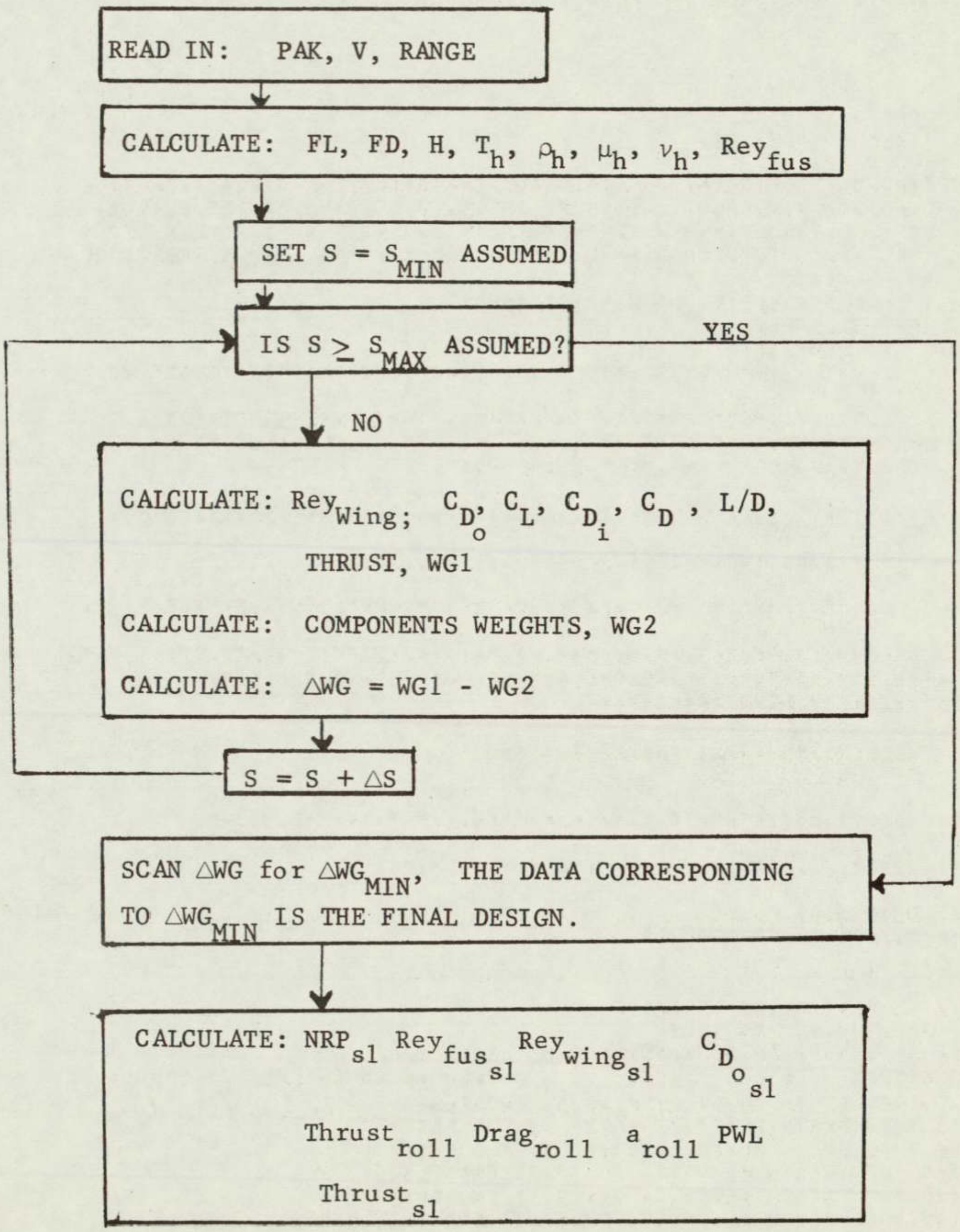


Figure 5-A-1

5-A-4 Computer Printout

The following computer printout is the actual Aircraft Parametric Design Model written in the B5500 Algol computer language.

```
        BURROUGHS B-5500 ALGOL COMPILER LEVEL  10      TUESDAY,   5/20/69,

   %USER= B481250, BIN 0478
   %COMPILE BIN0478/EE655    ALGOL            .13S800015   *0478 TAYLORHC
   %PROCESS=0015;ID=0030;ALGOL    PROCESS=15;ALGOL    ID=15,
   %DATA.
   %DATA TAYLIN .
   BEGIN

   FILE OUT PPN1 0(2,10);
   FILE OUT TAYLOUT 16(2,15);
   FILE IN TAYLIN (2,10);
   REAL    CDI,CD,CLF,CDF,CDIF,THRUST1,DRAG1,THRUSTSL,VEL,PAX,V,C1,C2,FL,
           D,FD,TEMPH,H,RHOH,MUH,NUH,REYFUS,S,AR,REYWING,CDOTOT,CL,WG1,
           WG2,LOD,THRUST,MIN,MAX,RANGE,CONST,K,OPW,SF,WGF1,WGF2,B,LODF,
           THRUSTF,CDOTOTF,HPSL,HPSLF,WGEMPT,NRPCR,NRPSL,ANN,R1,R2,CDOSL,
           AROL,RWL;
   REAL ARRAY    DELTAW,DEL[0:60],W,WFIN[0:18];
   INTEGER     I,J,LINCT;
   LABEL      L10,L20,L30;
   FORMAT    FMA("PAX",X1,"VEL",X2,"ALT",X2,"RANGE",X2,"WG1",X4,"WG2",X2,

             "OP.WGT",X1,"WGEMPT",X1,"THRCR",X1,"THRSL",X1,"THRIE",X1,
             "RLTHRT",X2,"HPSL",X1,"AREA",X1,"SPAN",X1,"LOD",X3,"RWL",X2,
             "CDCR",X2,"CDSL",X3,"FL",X3,"FD");

   FORMAT    FMAA(I3,X1,I3,X1,I5,X1,I4,X1,4(I6,X1),3(I5,X1),I6,X1,I5,X1,

             2(I4,X1),F4.1,X1,I4,X1,2(F5,3,X1),F5,1,X1,F4,1,/);

   FORMAT       FMDD(X2,"W(1)",X2,"W(2)",X2,"W(3)",X2,"W(4)",X2,"W(5)",X2,

              "W(6)",X2,"W(7)",X2,"W(8)",X2,"W(9)",X2,"W(10)",X2,"W(11)",X2,
             "W(12)",X2,"W(13)",X2,"W(14)",X2,"W(15)",X2,"W(16)",
              X2,"W(17)",X2,"W(18)");

   FORMAT    FMD(9(X1,I5),9(X2,I5),///);

   FORMAT    FMQ("12,",I2,",",I6,",",I6,",",F5.2,",",I6,",0.583,"

           ,I3,",",I4,",",I3,",4,2,",I4,",",I6,",");

   WRITE(TAYLOUT[NO]);
   READ(TAYLIN,/,C1,C2,AR,CONST);
   LINCT ← 0;
   ANN←4;
   FOR PAX ← 60,80,100,120 DO BEGIN
    FOR V ← 200,300,400 DO BEGIN
      FOR RANGE ← 200,400,600,800,1000 DO BEGIN
     IF V=200 THEN H← 15000 ELSE IF V= 300 THEN H← 20000 ELSE H← 25000;
   IF PAX=40 THEN BEGIN FL←64,0; FD←8,8; END ELSE
   IF PAX=60 THEN BEGIN FL←77.7; FD←10.5; END ELSE
   IF PAX=80 THEN BEGIN FL←80.0; FD←12.2; END ELSE
   IF PAX=100 THEN BEGIN FL←92.1; FD←12.2; END ELSE
   IF PAX=120 THEN BEGIN FL←98.5; FD←15.3; END ELSE
   IF PAX=140 THEN BEGIN FL←104.2; FD←15.3; END ELSE BEGIN
             FL←112.7; FD←15.3; END;
   L20: LINCT ← LINCT+1;
      ANN←ANN+1;
   IF LINCT = 61 THEN LINCT ← 1;
   VEL ← (V×88.0)/60.0;
```

```
DELTAW[(500+C1)/50-1] ← 1000000;
TEMPH ← 547-(0.003566×H);
RHOH ← (0.00226×(1.0-(0.00000687×H))*4.2561);
MUH ← (3.73@-07) ×((TEMPH/520)*1.5)×((718.7)/(TEMPH + 198.7));
NUH ← MUH/RHOH;
REYFUS ← ((VEL/NUH)×FL)*(1.0/7.0);
MIN ← 500+C1;    MAX ← 2000-C2;
FOR S ← MIN STEP 50 UNTIL MAX DO
 BEGIN
 REYWING ← ((VEL/NUH)×((S/AR)*0.5))*(1.0/7.0);
 CDOTOT ←1.21×((0.030/REYFUS)×((4×FL/FD)+(6×((FD/FL)*0.5))+(28×((FD/FL)
   *2)))×(3.1416×(FD*2)/(4.0×S))+(1.6×0.0744)/REYWING);
 CL ← (CDOTOT×3.1416×0.87×AR)*0.5;
IF CL>0.5 THEN CL←0.5;
 WG1 ← 0.5×CL×RHOH×S×(VEL*2);
CDI ← CL*2/(3.1416×0.87×AR);
CD ← CDOTOT + CDI;
LOD ← CL/CD;
 THRUST ← WG1/LOD;
W[1] ← 0.8×(FL*1.5)×(FD*0.25)×((4.5×WG1)*0.15);
W[2] ← (0.150-(0.063×WG1/100000))×WG1;
W[3] ← 0.035×WG1;
W[4] ← 0.04×WG1;
W[5] ← 140;
W[6] ← 550+40×PAX;
W[7] ← 500+(13×PAX);
W[8] ← 0.0005×(WG1*1.28);
W[9] ← 642;
W[10] ← 1.61×(WG1*0.55);
W[11] ← 0.02×WG1;
W[12] ← 200×(PAX+3);
IF PAX=56 THEN W[12]←45000;
W[13] ← WG1×(1-EXP(-(((RANGE+200+V×0.75)/375)×(1/LOD)×(0.55))));
W[14] ← 0.045×W[13];
  K ← (0.865-(0.55×H)/30000);
W[15] ← (THRUST×VEL/(CONST×K×325))×1.5;
D← 0.2×((AR×S)*0.5-FD);
HPSL← THRUST×VEL/(K×433);
W[16] ←56.8×(((D/10)*0.25)×((0.9×HPSL)*0.5)×0.5×3.1416×D*2×0.0041)*0.67;
W[17] ← 60×((0.6×1.11/500)×HPSL×D)*0.8;
W[18] ← 0.05×WG1;
   WG2 ← 0;
   FOR I← 1 STEP 1 UNTIL 18 DO  WG2← WG2+W[I];
   DEL[S/50] ← WG1-WG2;
   DELTAW[S/50] ← ABS(WG1 - WG2);
   IF DELTAW[S/50]<DELTAW[(S/50)-1] THEN BEGIN
     FOR J←1 STEP 1 UNTIL 18 DO   WFIN[J] ← W[J];
     SF←S;  WGF1←WG1;   WGF2←WG2;  B←(AR×SF)*0.5;  LODF←LOD;
     THRUSTF ← THRUST;     CDOTOTF←CDOTOT;     HPSLF←HPSL;
CLF ← CL;  CDF←CD;  CDIF←CDI;
    END;
    IF S≠MIN AND SIGN(DEL[S/50])=-(SIGN(DEL[(S/50)-1])) THEN GO TO L10;
    END;
L10:    NRPCR ← K×1.11×HPSLF;
OPW ← WGF2 -WFIN[13] -WFIN[12];
WGEMPT←OPW-0.667×WFIN[15]-WFIN[16]-WFIN[17];
NRPSL ← 1.11×HPSLF;
R1 ← (693000×FL)*(1/7.0);
R2 ←(693000×((SF/AR)*0.5))*(1/7.0);
CDOSL ←1.21×((0.03/R1)×((4×FL/FD)+(6×((FD/FL)*0.5))+(28×((FD/FL)
      *2)))×(3.1416×(FD*2)/(4.0×SF))+(1.6×0.0744)/R2);
THRUST1 ← (THRUSTF×VEL)/(62.2×K);
```

```
DRAG1 ← 7.78×CDOSL×SF;
AROL ← ((THRUST1−DRAG1)/WGF2−0.2)×32.17;
IF AROL ≥ 10.0 THEN AROL ← 10.0;
RWL ← 7020×1.5/AROL;
THRUSTSL ← NRPSL×2.5/4.0;
WRITE(TAYLOUT,FMA);
WRITE(TAYLOUT,FMAA,PAX,V,H,RANGE,WGF1,WGF2,OPW,WGEMPT,THRUSTF,4×THRUSTSL
      ,THRUSTSL,THRUST1,HPSLF,SF,B,LODF,RWL,CDF,CDOSL,FL,FD);
WRITE(TAYLOUT,FMDD);
WRITE(TAYLOUT,FMD,FOR I←1 STEP 1 UNTIL 18 DO WFIN[I]);
WRITE(PPN1,FMQ,ANN,WGF2,WFIN[17],LODF,THRUSTSL,V,RANGE−100,PAX,
      0.833×RWL,WGEMPT);
IF PAX=56 THEN GO TO L30;
   END;
   END;
   END;
PAX←56; V←300; H←25000; RANGE←2500; FL←98; FD←14; AR←11.0; GO TO L20;
L30:  END.
```

5-A-5 Design Model Output

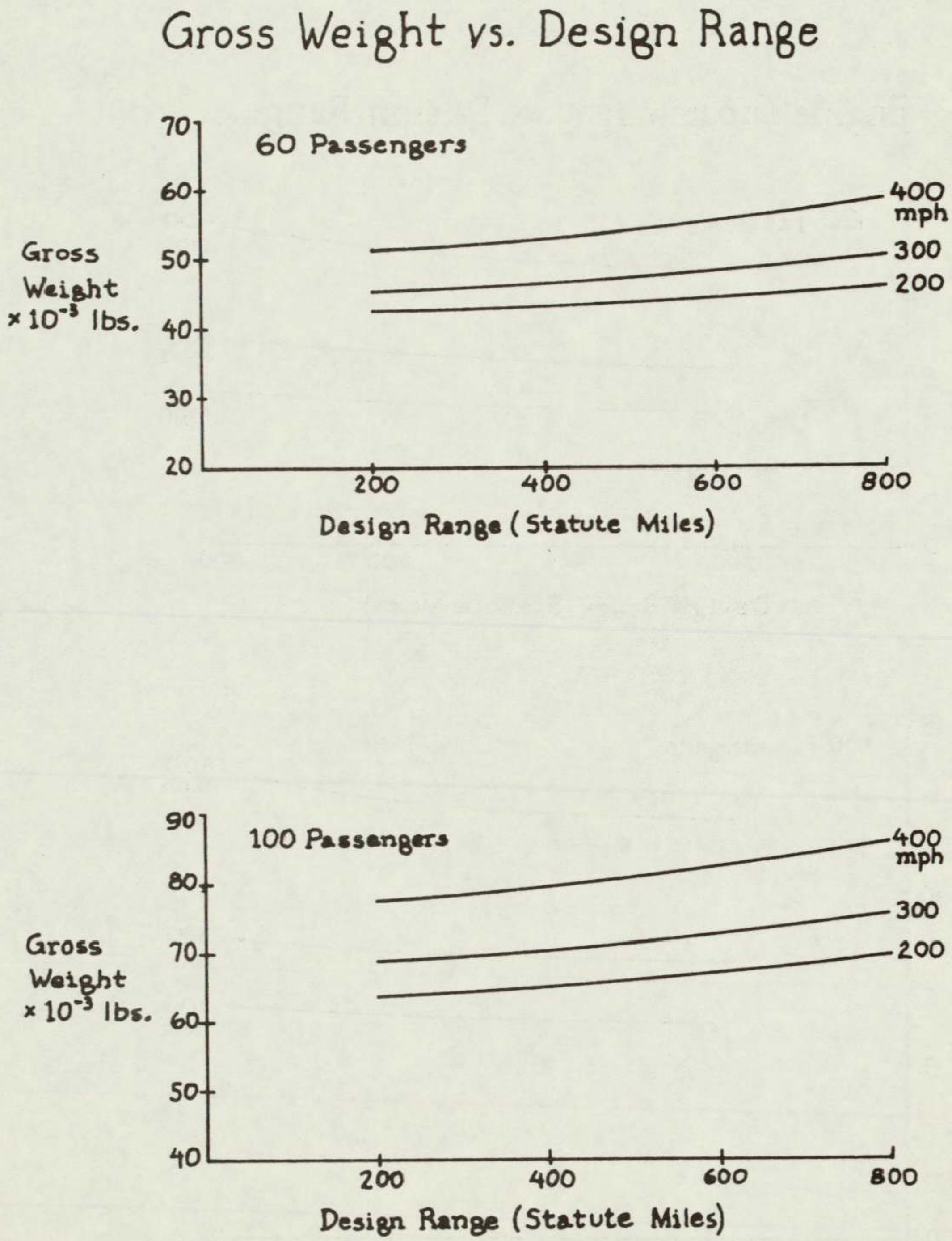
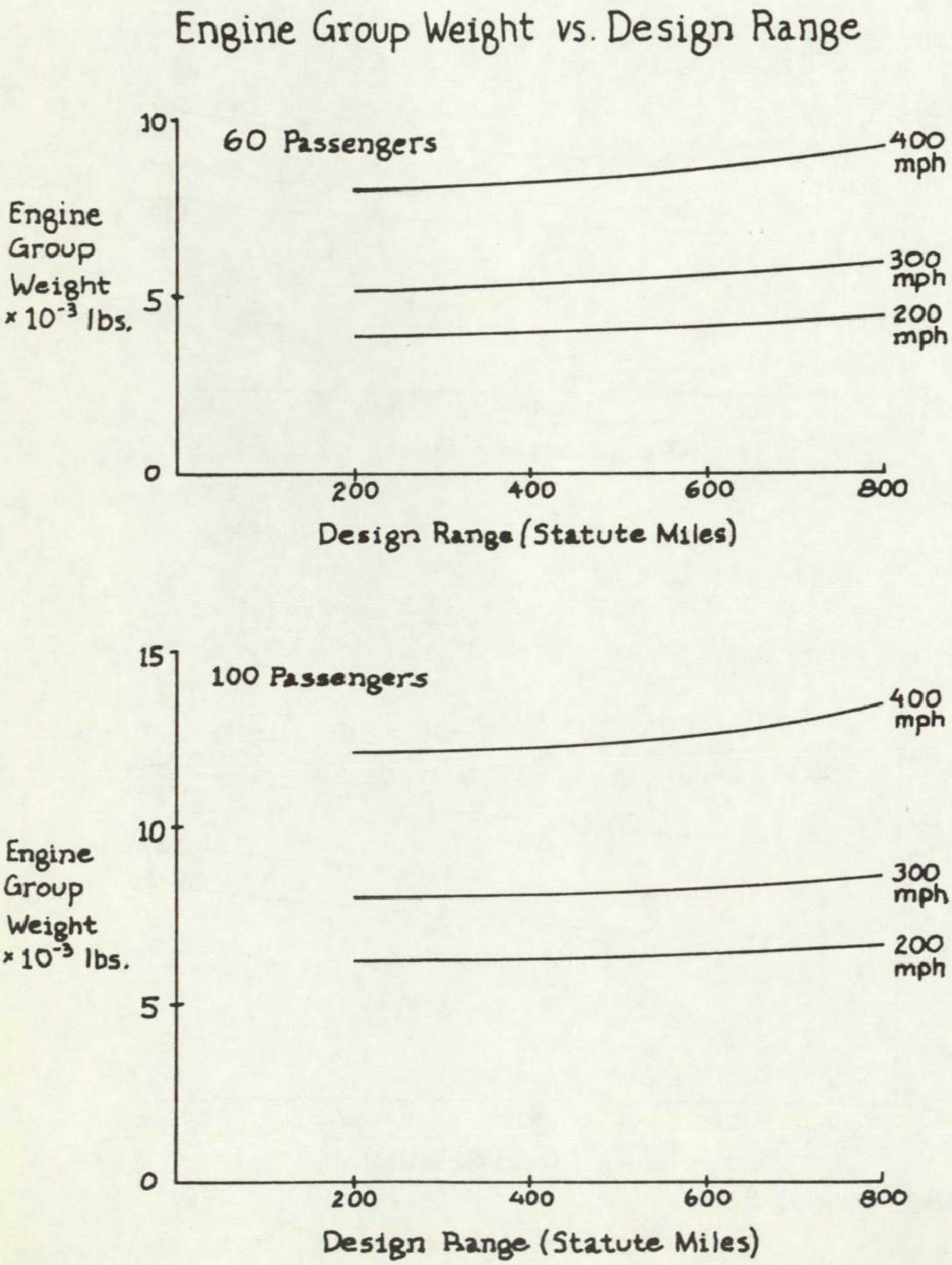


Figure 5-A-2



Engine Group Weight vs. Design Range
60 Passengers
Engine Group Weight × 10⁻³ lbs.
10
5
0
400 mph
300 mph
200 mph
200
400
600
800
Design Range (Statute Miles)
100 Passengers
Engine Group Weight × 10⁻³ lbs.
15
10
5
0
400 mph
300 mph
200 mph
200
400
600
800
Design Range (Statute Miles)

Figure 5-A-3

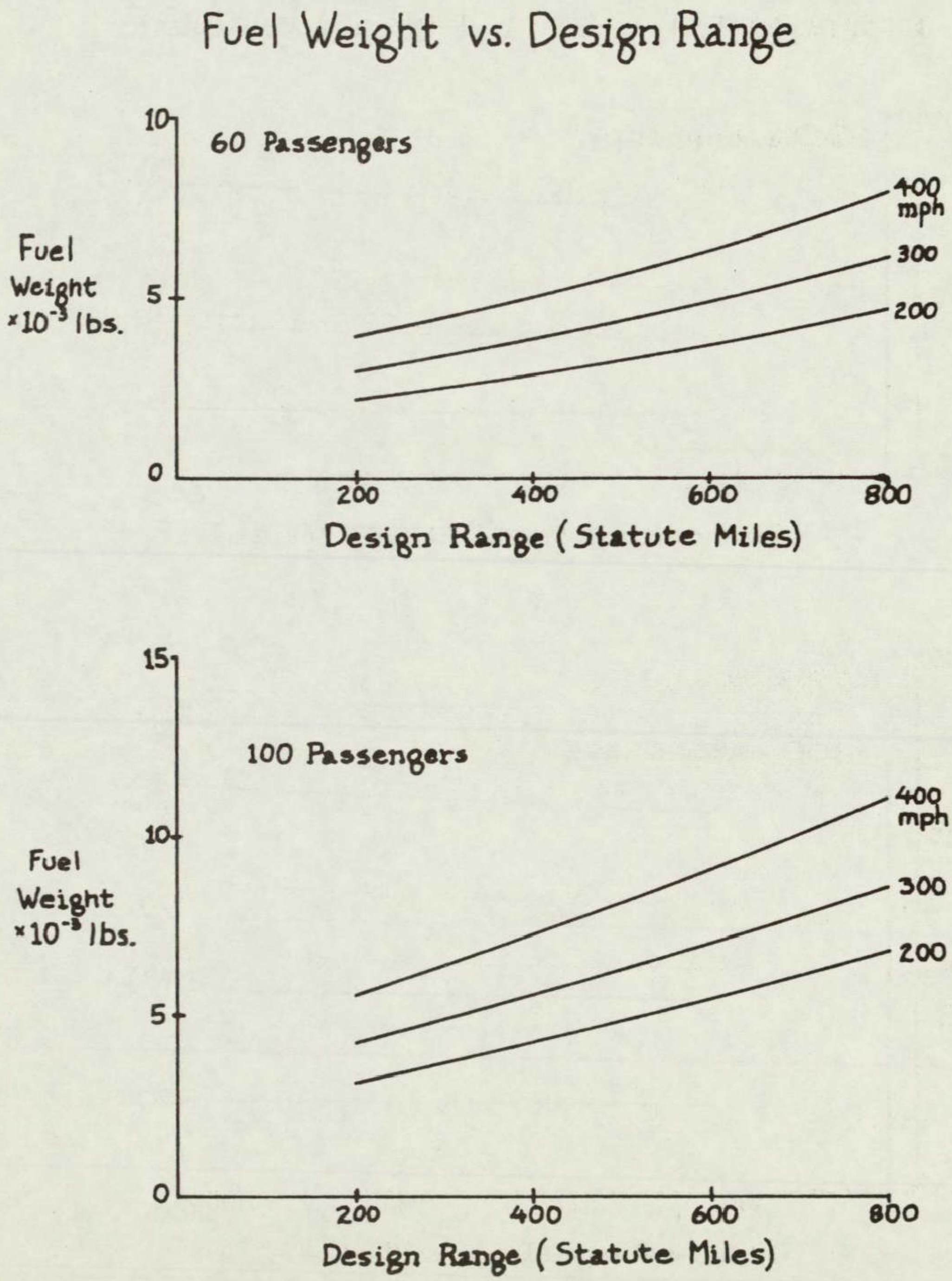
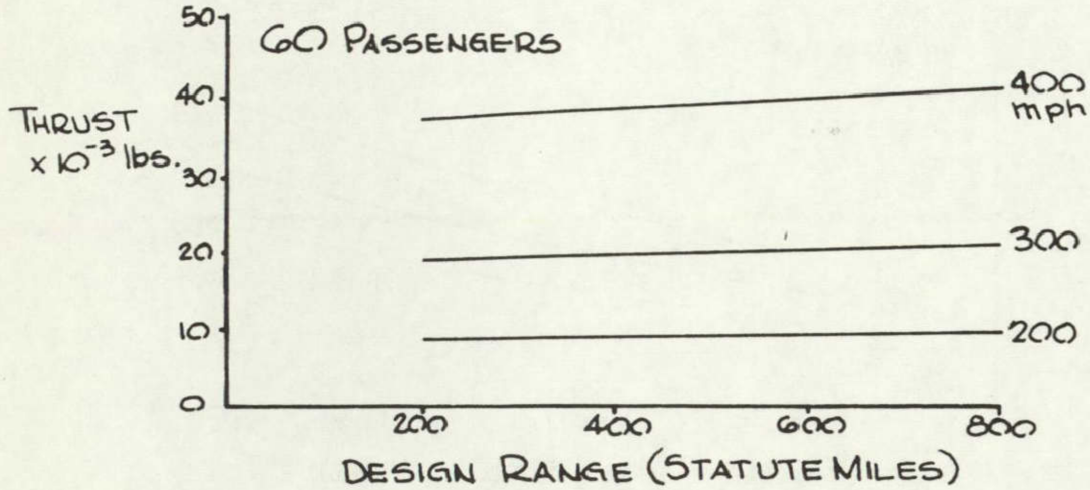

Fuel Weight vs. Design Range
60 Passengers
Fuel Weight ×10⁻³ lbs.
0
5
10
200
400
600
800
Design Range (Statute Miles)
400 mph
300
200
100 Passengers
Fuel Weight ×10⁻³ lbs.
0
5
10
15
200
400
600
800
Design Range (Statute Miles)
400 mph
300
200

Figure 5-A-4

THRUST vs. DESIGN RANGE



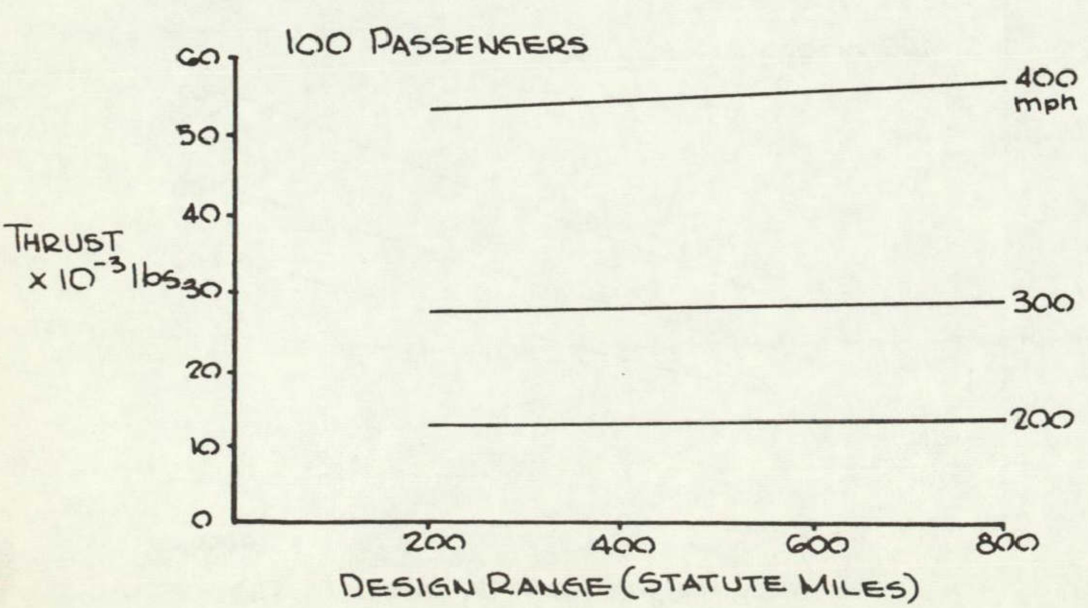
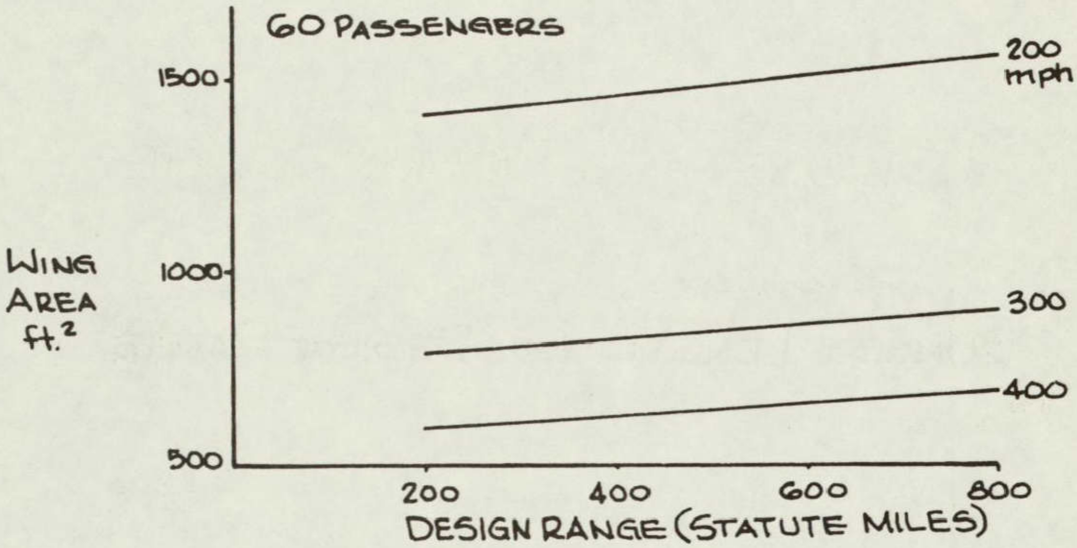


Figure 5-A-5

WING AREA VS. DESIGN RANGE



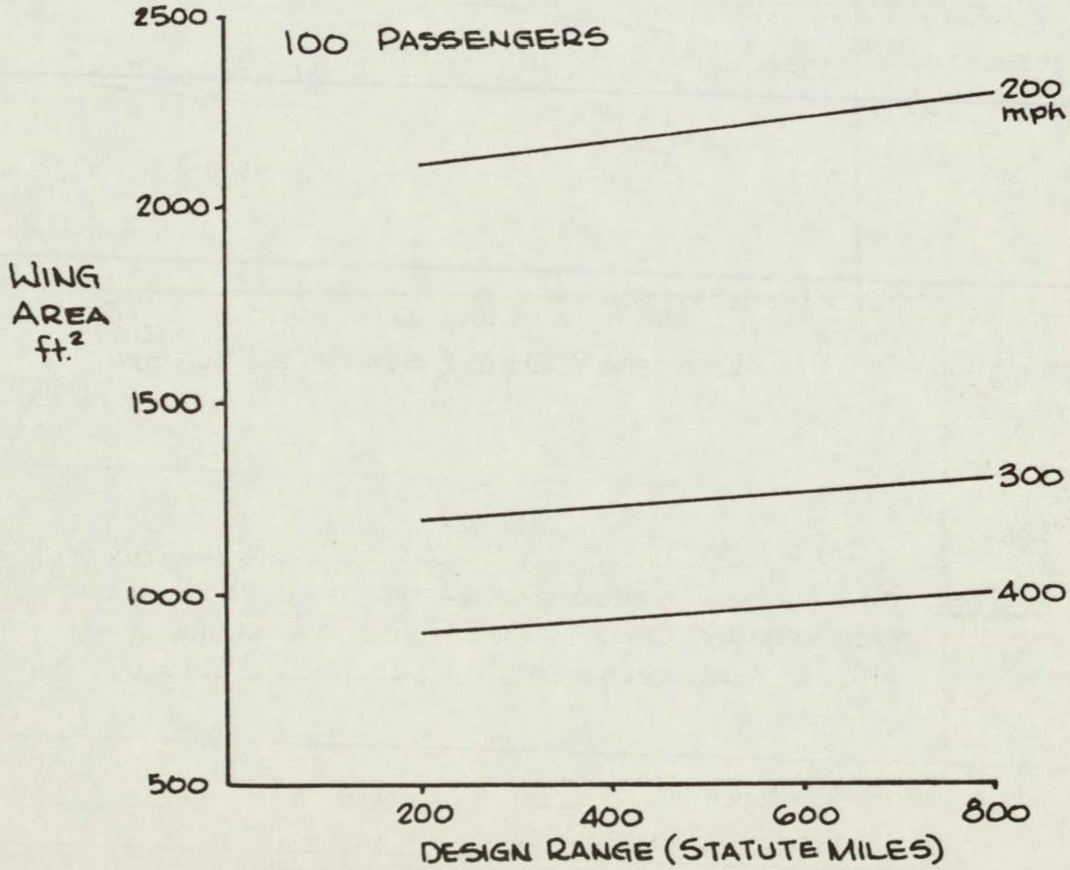
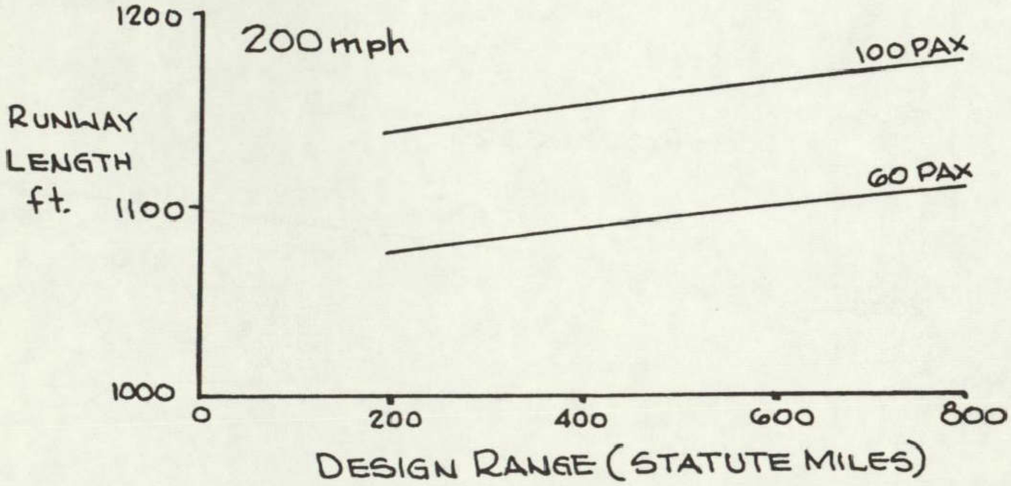


Figure 5-A-6

RUNWAY LENGTH VS. DESIGN RANGE



NOTE: FOR DESIGN SPEEDS GREATER THAN 200 mph THE RUNWAY LENGTH REACHES THE MINIMUM VALUE OF 1053 FEET.

Figure 5-A-7

APPENDIX 5-B

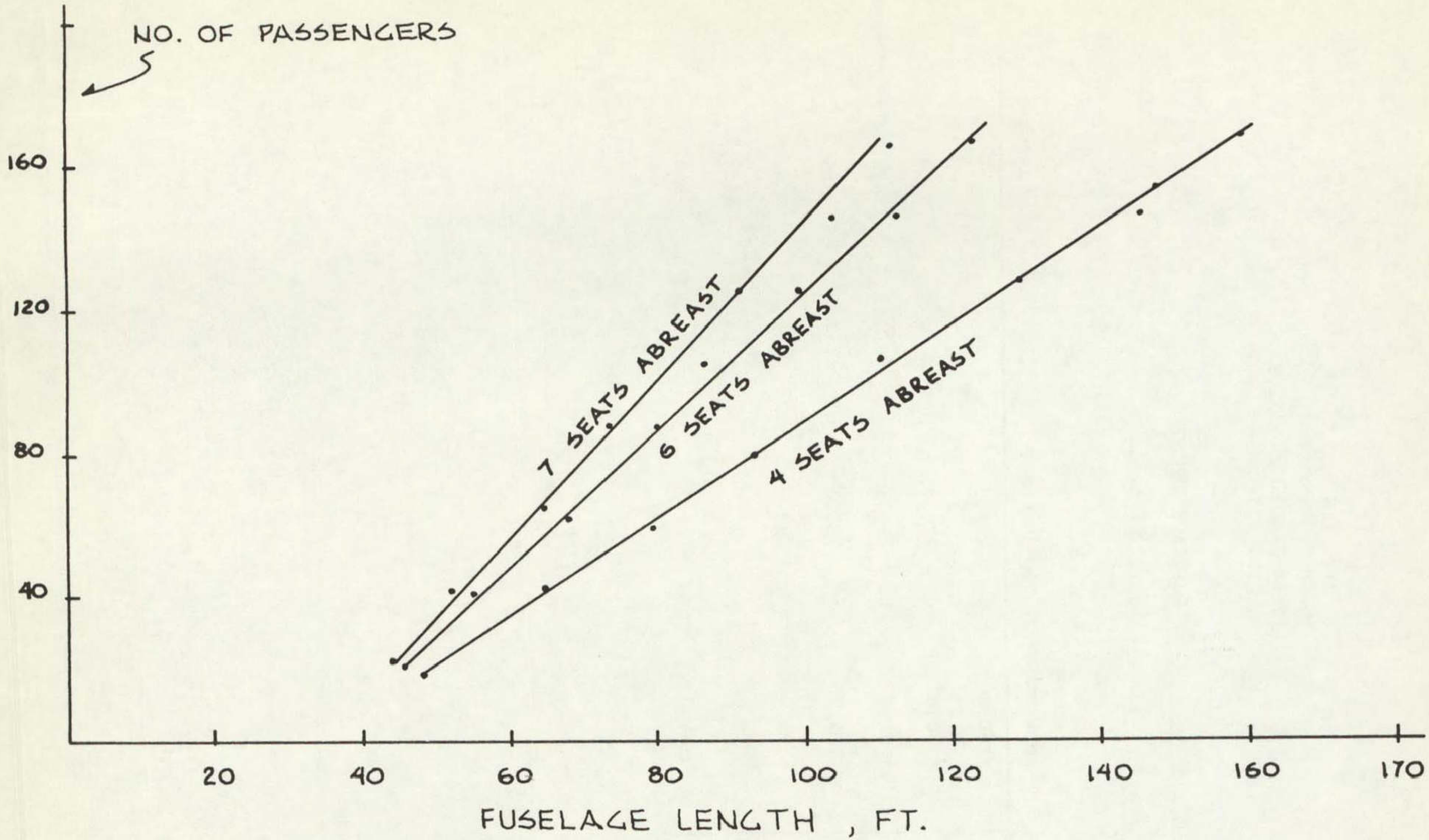
INTERIOR CONFIGURATION

FUSELAGE LENGTH

(Values in feet)

Passenger Load \ Seating Arrangement	4 Abreat	5 Abreast	6 Abreast	7 Abreast
160	160.8	138.2	124.0	52.8
140	146.6	126.8	115.6	64.9
120	132.5	115.5	104.3	73.4
100	114.7	100.3	92.1	86.3
80	96.0	89.0	80.0	98.5
60	81.9	77.7	67.7	104.2
40	64.0	58.3	55.5	112.7

Table 5-B-1



INTERIOR CONFIGURATION AND FUSELAGE LENGTH

Figure 5-B-1

APPENDIX 5-C

AIRCRAFT COST MODEL

[cost in millions of dollars]

5-C-1 Initial Cost Calculation:

- Initial Engineering (IE):

$$IE = 97.14 \times S^{0.547} (T \times NE)^{0.88} \times F_1 \times 10^{-6}$$

where B = Maximum Speed [Knots]

T = Thrust of one engine [lb]

NE = Number of engines

Fi = correction factor = 1 CTOL, 1.05 STOL

Engineering man hour cost = 12.10 $

- Development Support (DS):

$$DS = 1.29 \times IE$$

- Flight Test Operation (FT):

$$FT = 0.638 \times MGW^{0.80} \times S^{0.90} \times TA^{1.1} \times 10^{-6}$$

where:

MGW = Maximum gross weight [lb]

TA = Number of Test aircraft = 3

- Initial Tooling (IT):

$$IT = 1.45 \times S^{1.074} \times MGW^{0.839} \times F2 \times 10^{-6}$$

where:

F2 = correction factor = 1 CTOL, 1.05 STOL

tooling man hour cost = 11.84 $

- Sustaining Engineering (SE):

$$SE = IE\ (N2^{0.20} - N1^{0.20})$$

where:

N2 = Final number of aircraft in production run

N1 = initial number of aircraft in production run

- Sustaining Tooling (ST):

$$ST = IT\ (N2^{0.138} - N1^{0.138}) \times R^{0.4}$$

where:

$$R = \text{Production rate}\ [\ \frac{\text{aircraft}}{\text{month}}\ ] = 10$$

- Manufacturing Labor (TL):

$$TL = \frac{120.47 \times MGW^{0.737} \times S^{0.431}\ [(N2 + 0.5)^{0.585} - 0.666] \times F3}{0.585 \times 10^{6}}$$

where:

F3 = correction factor = 1 CTOL, 1.05 STOL

Labor man hour cost = 9.67 $

- Materials (TM):

$$TM = \frac{0.4093 \times MGW^{0.779} \times S^{0.856}\ [(N2 + 0.5)^{0.832} - 0.561] \times F4}{0.832 \times 10^{6}}$$

where F4 = correction factor = 1

- Engine initial development cost (EID):

- Turboprop engine:

$$EID = 2.044 \times T^{0.355} \times (N \times NE)^{0.093} \times F5.$$

- Turbofan Engine:

$$EID = 0.1394 \times T^{0.744} \times (N \times NE)^{0.077} \times F5.$$

where:

F5 = correction factor = 1

- Engine Production Cost (TPCE):

- Turboprop Engine

$$TPCE = 3.19 \times T^{0.459} \times (N2^{0.891} - N1^{0.891}) \times F6 \times 10^{-3}$$

where:

$N2$ = Final number of Engines in Production Run

$N1$ = Initial number of Engines in Production Run

$F6$ = correction factor = 1 CTOL, 2.04 STOL (for consideration of the cost of propellers and gear systems)

- Turbofan Engine:

$$TPCE = [TFW \times 0.187 \times T^{0.848} + TFN \times 0.3198 \times T^{0.816}] \times [TFW \times (N2^{0.867} - N1^{0.867}) + TFN\ (W2^{0.871} - N1^{0.871})] \times F6 \times 10^{-3}$$

where:

TFW = Turbofan weighting factor applied to a turbojet with afterburner = 0.5

TFN = Turbofan weighting factor applied to turbojet with no afterburner = 1 - TFW

- Furnishing Equipment (TFE):

$$TFE = 2.5 \times PAX \times N \times F7 \times 10^{-3}$$

where:

PAX = Number of Passengers

N = Production Run

F7 = Correction factor = 1

5-C-2 Direct Operating Cost Calculation [cost in $/mile]:

- Flying operations:

- Flight Crew (FC):

$$FC = (0.05 \times \frac{MGW}{10^3} + CRW)/VBLK$$

where: $CRW = \text{constant} = \begin{cases} 63 \text{ - Turboprop and two man crew} \\ 100 \text{ - Turboprop and three man crew} \\ 98 \text{ - Turbofan and two man crew} \\ 135 \text{ - Turbofan and three man crew} \end{cases}$

VBLK = Clock speed [mph]

- Fuel and Oil (FO):

$$FO = \frac{1.02}{D} \times (0.01642 \times FBLK + 0.125 \times NE \times TBLK)$$

where

D = Range [miles]

FBLK = Block fuel

TBLK = Block Time

- Hull Insurance (HI):

$$HI = \frac{0.02 \times UNITCOST \times 10^6}{U \times VBLK}$$

where:

UNITCOST = cost of one airplane [$ millions]

U = Utilization factor [hr/year]

- Direct Maintenance:

- Airframe Labor (AL):

$$AL = \frac{KFC \times [0.59 \times TF + 1] \times 4}{VBLK \times TBLK}$$

where:

$$KFC = [\ \frac{0.05\ WE}{10^3}\ ] + 6 - \frac{630}{(\frac{WE}{10^3} + 120)}]$$

WE = Empty weight less engines [lb]

TF = Flight time.

- Airframe Materials (AM):

$$AM = \frac{(3.08 \times TF + 6.24) \times (UNITCOST - NE \times UNITEC)}{VBLK \times TBLK \times}$$

where:

UNITEC = unit engine cost [$ millions]

- Engine Labor (EL):

$$EL = \frac{(KFH \times TF + KFE) \times 4}{VBLK \times TBLK}$$

where:

$$KFH = \left(0.65 + \frac{0.03\ T}{10^3} \right) NE \quad \textbf{(Turboprop)}$$

$$KFH = \left(0.60 + \frac{0.027\ T}{10^3} \right) NE \quad \textbf{(Turbofan)}$$

- <u>Propeller gear system labor</u> (GL):

$$GL = \frac{(0.57 + 0.00018 \times WG) \times 4}{VBLK}$$

where:

WG = weight of the transmission (lb)

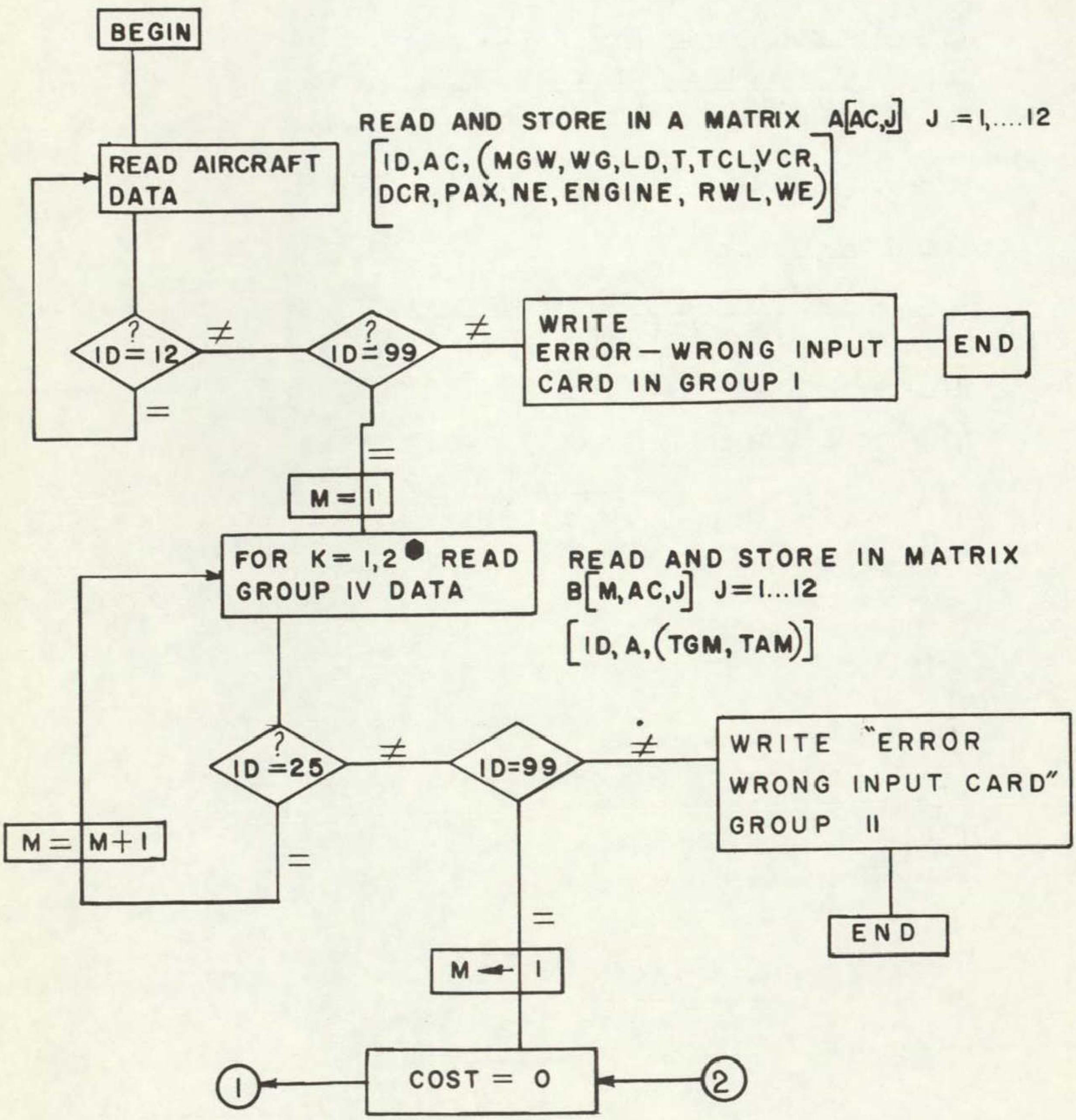
- <u>Engine Material</u>

$$EM = \frac{(2.5 \times TF + 2.0) \times NE \times UNITEC \times 10}{VBLK \times TBLK}$$

- <u>Maintenance Burden</u> (MB):

$$MB = 1.8 \times (AL + EL)$$

COST MODEL FLOW CHART



NOTE

● Since the aircraft mix are formed by two aircraft only the read statement is performed twice for each value of M.

KEY

K = counter = 1,2
ID = card identification 12, 25, 15
AC = aircraft number 1,....to 66
M = mix number 1,2,....37

Figure 5-C-1

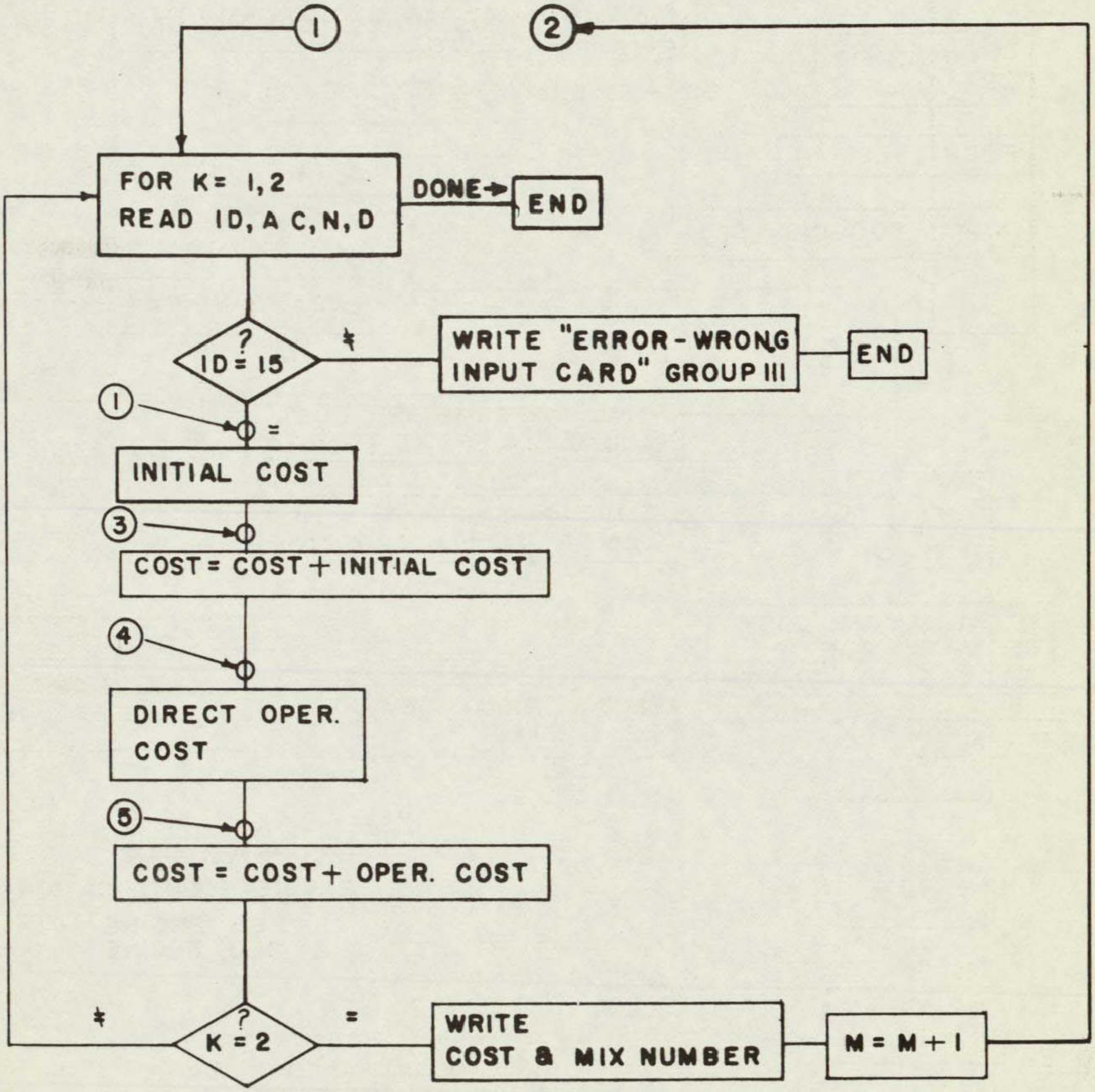
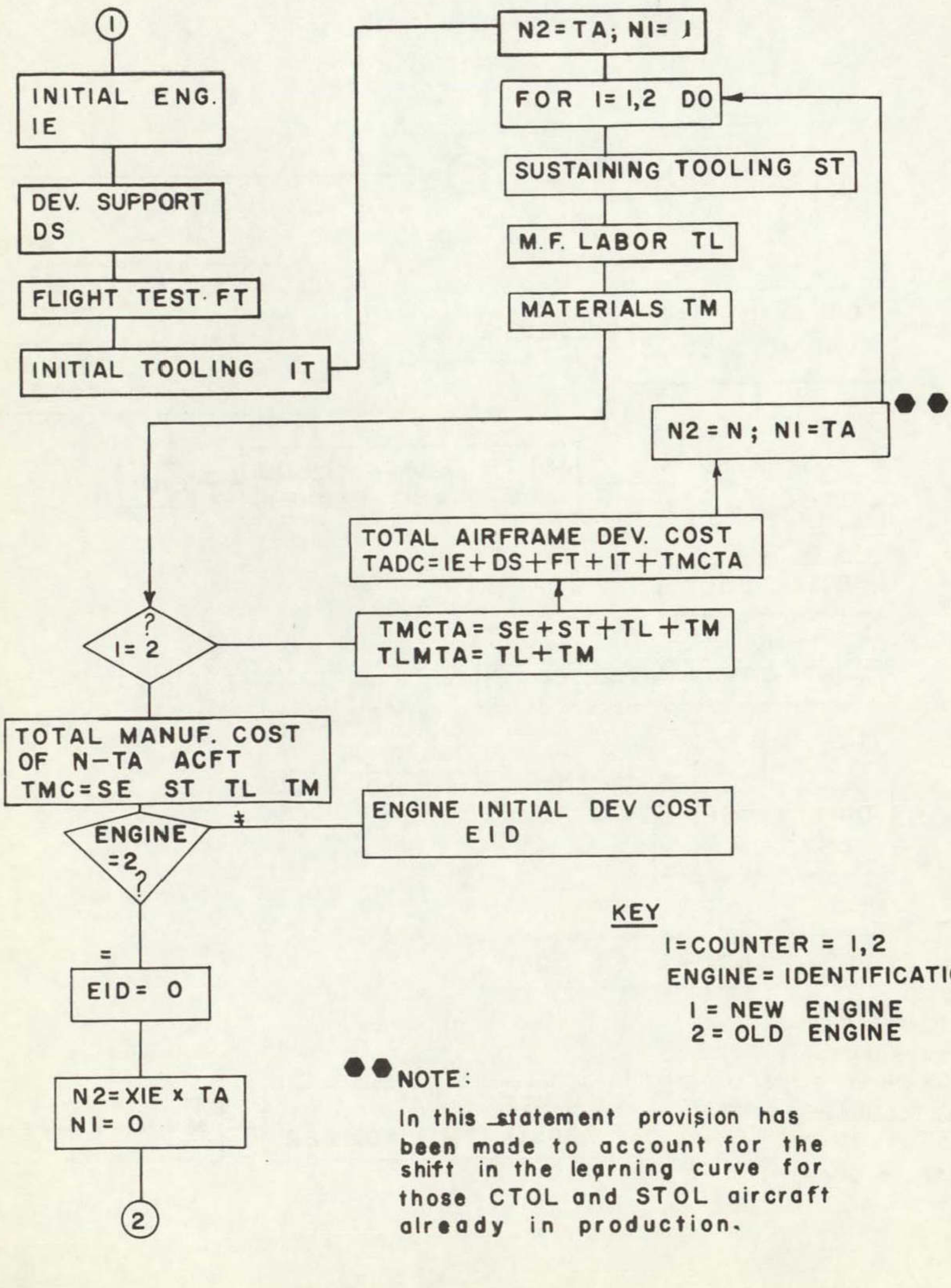


Figure 5-C-1 Continued

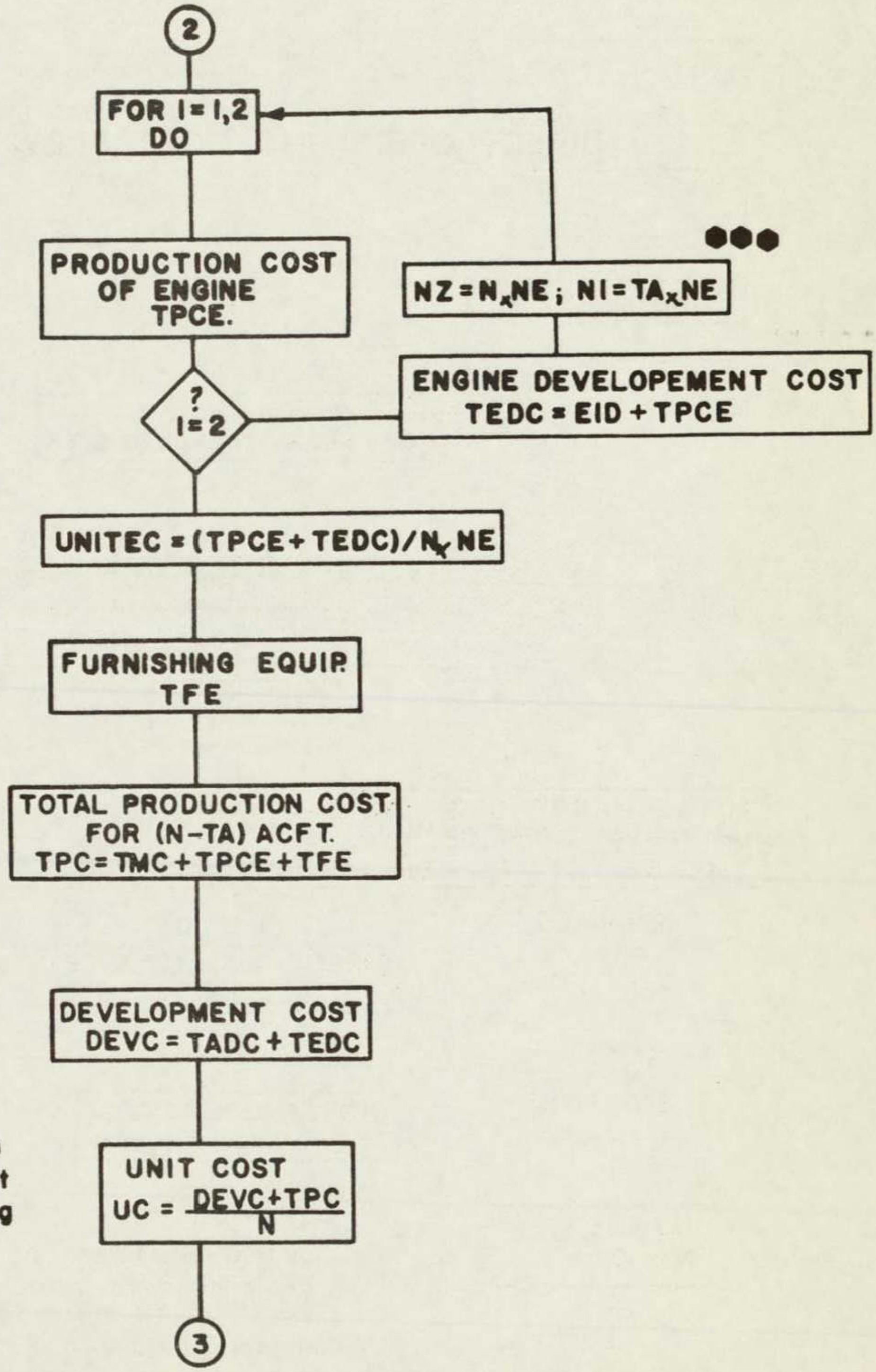
INITIAL COST FLOW CHART



KEY
I=COUNTER = 1,2
ENGINE= IDENTIFICATION
1 = NEW ENGINE
2 = OLD ENGINE

●● NOTE:
In this statement provision has been made to account for the shift in the learning curve for those CTOL and STOL aircraft already in production.

Figure 5-C-2



NOTE:
In this statement provision has been made to account for the shift in the learning curve for those CTOL and STOL aircraft already in production.

Figure 5-C-2 Continued

DIRECT OPERATING COST FLOW CHART

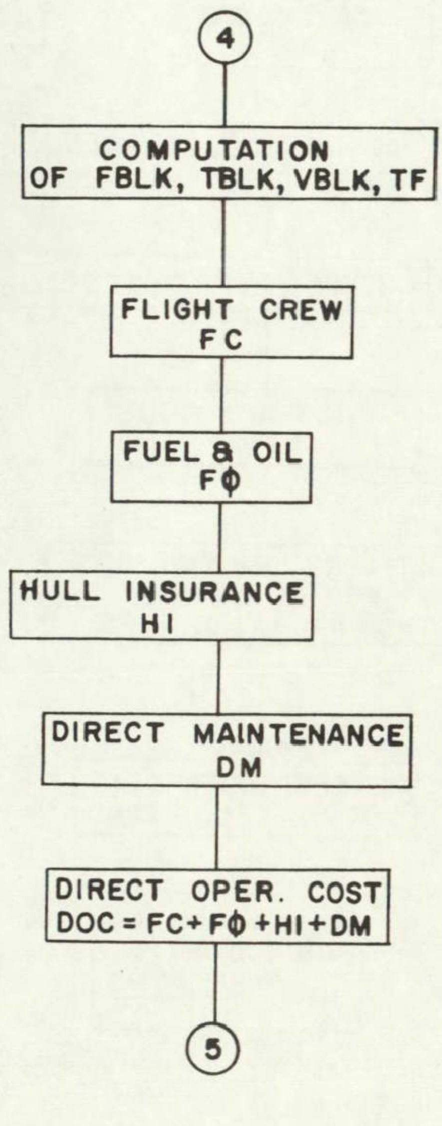


Figure 5-C-3

5-C-3 Computer Printout

The following computer printout is the actual Aircraft Cost Model written in the Algol B5500 computer language.

```
%
BEGIN

FILE IN  ENTRA (2,10);
FILE OUT SALE 16(2,15);
INTEGER  M,K;
INTEGER  NE,TA,N,N1,N2,I,J,R,CRW,PAX,AC,ID,ENGINE;
REAL     EID,F5,TPCE,F6,TFW,TFN,TEDC,UNITEC,TFE,F7,TPC,DEVC,TLMTA;
REAL     IE,S,T,F1,DS,FT,MGW,F2,IT,SE,ST,TL,F3,TM,F4,TMCTA,TADC,TMC;
REAL     UNITCOST,D,VCR,TCR,VBLK,TGM,TCL,TAM,TBLK,TF,FCR,FBLK,FC,FO,U;
REAL     HI,KFC,WE,AL,AM,LD,DCR,COST,KFH,EL,EM,MB,KFE,DOC,WG,DM,RWL;
REAL     ARRAY A[0:99,0:14];
REAL     ARRAY B[0:37,0:99,0:2] ;
LABEL    L1,L2,LB1,LB2,LB4,LB6,LB8,DONE,LB3;
FORMAT   FM1(/,/,"ERROR CARD ID ≠ 12 IN FIRST GROUP");

FORMAT   FM2(/,/,"ERROR CARD ID ≠ 25 IN SECOND GROUP A");

FORMAT   FM3(/,/,"ERROR CARD ID ≠ 15 IN SECOND GROUP B");

FORMAT   FM6(/,/,"COST=",I14,X10,"MIX NUMBER",I4,/,/) ;

FORMAT   FM7(I9,F14.3,F12.3,I7,F10.3,F10.3,F9.2,F8.2,F8.2,I7,I9,2I6);

FORMAT   HEAD(X5,"AIRCRAFT",X4,"DEVC",X8,"TPC",X8,"N",X4,"UNITCOST",X4,
         "UNITEC",X3,"DOC",X5,"FUEL",X4,"DM",X7,"D",X6,"MGW",
         X4,"VCR",X3,"PAX",/);

         WRITE(SALE[NO]);
         WRITE(SALE,HEAD);
LB1:     READ(ENTRA,/,ID,AC,FOR J←1 STEP 1 UNTIL 12 DO A[AC,J]);
         IF ID ≠ 12 AND ID ≠ 99 THEN BEGIN
         WRITE(SALE,FM1); GO TO DONE ; END ELSE
         IF ID = 12 THEN GO TO LB1  ELSE
         M ← 1 ;
LB2:     READ(ENTRA,/,ID,AC, FOR J←1,2  DO  B[M,AC,J]);
         IF ID ≠ 25 AND ID ≠ 99 THEN BEGIN
         WRITE(SALE,FM2); GO TO DONE ; END ELSE
         IF ID = 99 THEN GO TO LB6 ELSE
         READ(ENTRA,/,ID,AC, FOR J←1,2  DO  B[M,AC,J]);
         IF ID ≠ 25 AND ID ≠ 99 THEN BEGIN
         WRITE(SALE,FM2); GO TO DONE ; END ELSE
         M ← M+1 ;
         GO TO LB2 ;
LB6:     M ← 1 ;
LB3:     COST ← 0 ;
         FOR K ← 1,2 DO  BEGIN
         READ(ENTRA,/,ID,AC,N,D)[DONE];
         IF ID ≠ 15  THEN BEGIN  WRITE(SALE,FM3); GO TO DONE ; END;
         IF N=0 THEN  GO TO LB8 ELSE N←N×10 ;
```

```
        MGW ← A[AC,1] ;
        WG ← A[AC,2] ;
        LD ← A[AC,3] ;
        T ← A[AC,4] ;
        TCL ← A[AC,5];
        VCR ← A[AC,6];
        PAX ← A[AC,8];
        NE ← A[AC,9];
        ENGINE ← A[AC,10];
        RWL ← A[AC,11] ;
        WE ← A[AC,12] ;
        TGM ← B[M,AC,1] ;
        TAM←B[M,AC,2] ;
        S ← 1.10×VCR×0.8684 ;
COMMENT INITIAL COST CALCULATION ;
        BEGIN
        F1←F2←F3←F4←F5←F6←F7←1  ;
        TFW←0.5 ;   R←10 ;  TA ← 3 ;
        IF AC > 4 THEN BEGIN
        F1←F1×1.05 ; F2←F2×1.05; F3←F3×1.05;F5←F5×1.10;F6←F6×2.04;END;
        TFN ← 1.0 - TFW ;
COMMENT INITIAL ENGINEERING ;
        IE ←97.14×S*0.547×(T×NE)*0.88×@-6×F1 ;
COMMENT DEVELOPMENT SUPPORT ;
        DS ← 1.29×IE ;
COMMENT FLIGHT TEST OPERATION ;
        FT ← 0.638×MGW*0.80×S*0.90×TA*1.1×@-6 ;
COMMENT INITIAL TOOLING ;
        IT ← 1.45×S*1.074×MGW*0.839×@-6×F2 ;
        N2 ← TA ;  N1 ← 1 ;
        FOR I ← 1,2 DO BEGIN
COMMENT SUSTAINING ENGINEERING ;
        SE ← IE×(N2*0.20 - N1*0.20) ;
COMMENT SUSTAINING TOOLING ;
        ST ← IT×(N2*0.138 - N1*0.138)×R*0.4 ;
COMMENT MANUFACTURING LABOR ;
        TL ← 120.47×MGW*0.737×S*0.431×((N2+0.5)*0.585 - 0.686)×F3/
             (0.585×@6) ;
COMMENT MATERIALS ;
        TM ← 0.4093×MGW*0.779×S*0.856×((N2+0.5)*0.832 - 0.561)×F4/
             (0.832×@6) ;
COMMENT TOTAL MANUFACTURING COST FOR TEST AIRCRAFTS;
        IF I = 2  THEN  GO TO L1  ELSE
        TMCTA ← SE+ST+TL+TM ;
        TLMTA ← TL +TM ;
COMMENT TOTAL AIRFRAME DEVELOPMENT COST ;
        TADC ← IE+DS+FT+IT+TMCTA ;
        IF AC =  1 THEN BEGIN
        N2 ← 200+N ;  N1 ← 200 ; END ELSE
        IF AC=4  OR  AC=65  THEN BEGIN
        N2 ← 300+N ;
        N1 ← 300     ; END ELSE
```

```
         IF AC = 66 THEN BEGIN
         N2 ← 10+N ;
         N1 ← 10    ; END ELSE
         N2 ← N ; N1 ← TA ;
         IF N2 > 1000  THEN N2 ← 1000 ;
         END OF TEST AIRCRAFTS CALCULATION ;

COMMENT  TOTAL MANUFACTURING COST OF (N-TA) AIRCRAFTS ;
L1:      IF  AC≤ 4  OR  AC≥65  THEN BEGIN
       TLMTA←120.47×MGW*0.737×S*0.431×((N1+0.5)*0.585 - 0.666)×F3/
              (0.585×@6) ;
   TLMTA←TLMTA+0.4093×MGW*0.779×S*0.856×((N1+0.5)*0.832 - 0.561)×F4/
              (0.832×@6) ;
         END;
         TMC ← SE+ST+TL+TM -TLMTA ;
         TMC ← TMC/(N2-N1) ;

COMMENT  ENGINE INITIAL DEVELOPMENT COST ;
         IF ENGINE =  2   THEN EID ← 0 ELSE
         IF AC > 4 THEN
         EID ← 2.044×T*0.355×(N×NE)*0.093×F5   ELSE
         EID ← 0.1394×T*0.744×(N×NE)*0.077×F5 ;

COMMENT  ENGINE TOTAL PRODUCTION COST ;
         N2 ← TA×NE ; N1 ← 0 ;
         FOR I ← 1,2 DO  BEGIN
         IF AC > 4 THEN
         TPCE ← 3.19×T*0.459×(N2*0.891 - N1*0.891)×F6×@-3 ELSE
         TPCE ← (TFW×0.187×T*0.848 + TFN×0.3198×T*0.816)×(TFW×(N2*0.867
               - N1*0.867) + TFN×(N2*0.871 - N1*0.871))×F6×@-3 ;
         IF I=2 THEN GO TO L2 ELSE

COMMENT  ENGINE TOTAL DEVELOPMENT COST ;
         TEDC ← EID + TPCE ;
         IF AC =  1 THEN BEGIN
         N2 ←(200+N)×NE ;  N1 ← 200×NE  ; END ELSE
         IF AC = 66 THEN BEGIN
         N2 ← (10+N)×NE;
         N1 ← 10×NE ; END ELSE
         IF AC=4  OR  AC=65  THEN BEGIN
         N2 ←(300+N)×NE ;
         N1 ← 300×NE ; END ELSE
         N2 ← N×NE ; N1 ← TA×NE ;
         IF N2 > 2000  THEN N2 ← 2000 ;
         END OF ENGINE PROCUREMENT COST CALCULATION FOR TEST AIRCRAFTS;
L2:      UNITEC ← TPCE/(N2 - N1) ;

COMMENT  TOTAL FURNISHING EQUIPMENT ;
         TFE ← 2.5×PAX×N×F7×@-3 ;

COMMENT  TOTAL PRODUCTION COST FOR (N-TA) AIRCRAFTS ;
         TPC ← TMC×N  + UNITEC×N×NE + TFE  ;

COMMENT  TOTAL DEVELOPMENT COST ;
         IF  AC ≤ 4  OR  AC ≥ 65  THEN  DEVC ← 0  ELSE
         DEVC ← TADC + TEDC ;
         UNITCOST ← (DEVC + TPC)/N ;
         COST ← COST +(DEVC×2.399 + TPC×2.014)×@5;
         END;

COMMENT  DIRECT OPERATING COST CALCULATION ;
```

```
        BEGIN
        IF AC > 4 THEN BEGIN
        DCR ← D- 100 ;
        FCR ← MGW×(1-EXP(-DCR/(683×LD))) ;
        IF VCR = 200 THEN
        FBLK ← FCR + 950×MGW/@5 ELSE
        IF VCR = 300 THEN
        FBLK ← FCR+1290×MGW/@5 ELSE
        FBLK ← FCR+1640×MGW/@5 ; END ELSE
        IF D ≥ 600 THEN BEGIN
        DCR ← D-280 ;
        FBLK ← (5000+13,4×DCR)×MGW/@5 ; END ELSE
        BEGIN
        DCR ← D-140 ;
        FBLK ← (3000+15,6×DCR)×MGW/@5 ; END;
        TCR ← (1,015×D+27-(D-DCR))/VCR ;
        VBLK ← D/(TGM+TCL+TCR+TAM) ;
        TBLK ← D/VBLK ;
        TF ← TBLK-TGM ;

COMMENT FLYING OPERATIONS
          FLIGHT CREW ;
        IF MGW ≤120000 THEN BEGIN
        IF   AC > 4         THEN CRW ← 63 ELSE CRW ← 100 ; END;
        IF   AC > 4         THEN CRW  ←98 ELSE CRW ← 135;
        FC ←(0,05×MGW/@3 + CRW)/VBLK ;

COMMENT   FUEL AND OIL ;
        FO ←(1,02/D)×(0,01642×FBLK + 0,125×NE×TBLK)  ;

COMMENT   HULL INSURANCE ;
        IF TBLK ≤ 2 THEN
        U ← 1586,6+1673,4×TBLK-316,8×TBLK*2 ELSE
        IF TBLK > 2 AND TBLK≤ 3 THEN U←3600+(TBLK-2)×400 ELSE
        IF TBLK > 3 AND TBLK ≤ 4 THEN U←4000+(TBLK-3)×200 ELSE
        IF TBLK> 4 AND TBLK ≤ 5 THEN U←4200+(TBLK-4)×100 ELSE U←4400;
        HI ← 0,02×UNITCOST/(U×VBLK)×@6 ;

COMMENT DIRECT MAINTENANCE
          AIRFRAME LABOR ;
        KFC ← (0,05×WE/@3)+ 6 -(630/(WE/@3+120)) ;
        AL ← KFC×(0,59×TF+1)×4/(VBLK×TBLK)  ;

COMMENT   AIRFRAME MATERIAL  ;
        AM ← (3,08×TF+6,24)×(UNITCOST-NE×UNITEC)/(VBLK×TBLK);

COMMENT   ENGINE LABOR  ;
        KFE ←(0,3+0,03×T/@03)×NE ;
        IF   AC > 4        THEN KFH←(0,65+0,03×T/@3)×NE ELSE
        KFH ←(0,60+0,027×T/@03)×NE ;
        EL ←(KFH×TF+KFE)×4/(VBLK×TBLK) ;
        IF   AC > 4         THEN EL←EL+(0,57+0,00018×WG)×4/VBLK ELSE

COMMENT   ENGINE MATERIALS ;
        EM ← (2,5×TF+2,0)×NE×UNITEC/(VBLK×TBLK)×10;

COMMENT   MAINTENANCE BURDEN ;
        MB ← 1,8×(AL+EL)  ;
        DM ← AL+AM+EL+EM+MB ;
        IF   AC > 4        THEN DM ←DM×1,10  ;

        DOC ← FC+FO+HI+DM;
```

```
          WRITE(SALE,FM7,AC,DEVC,TPC,N,UNITCOST,UNITEC,DOC,FO,DM,D,
          MGW,VCR,PAX);
          COST ← COST + DOC×VBLK×U×1.3972×N ;
   LB8:   END ;
          END;
          WRITE(SALE,FM6,COST,M+117) ;
          M ← M+1 ;
          GO TO LB3;
   DONE:
   END.
```

APPENDIX 5-D

CTOL AIRCRAFT INFORMATION USED IN THE ROUTE MODEL

5-D-1

Nomenclature

PAX - Maximum number of passenger sears on the aircraft.

CRS - Cruise speed.

MAXR - Maximum useable range at full passenger capacity.

TCDL - Average number of minutes to take off, climb to cruise altitude, descend and land.

3/8UR - 3/8 of the maximum range considered in the route model. UR equals MAXR for those aircraft with a maximum useable range less than 2000 miles. For aircraft with a maximum useable range greater than 2000 miles, UR is set at 2000 miles due to the arrangement of the cities in the route model.

1/4CUR - Cents per mile operating cost at one fourth of the useable range (UR).

5/8 UR - 5/8 of the useable range (UR).

1/2CUR - Cents per mile operating cost at one half of the useable range (UR).

7/8UR - 7/8 of the useable range (UR).

3/4CUR - Cents per mile operating cost at 3/4 of the useable range (UR).

UR - Useable range considered for the route model.

1/8UR - 1/8 of the useable range (UR). This is the point below which aircraft are not considered, for any leg in the route model.

The above information is portrayed in tabular form in Table 5-D-1.

CTOL AIRCRAFT INFORMATION

AIRCRAFT	L-1011	747	727-200	DC-9 Series 30
PAX	300	490	178	115
CRS	575	625	517	557
MAXR	5290	8000	2300	1725
TCDL	30	39	23	25
3/8UR	750	750	750	563
1/4CUR	223	359	133	102
5/8UR	1250	1250	1250	938
1/2CUR	198	335	120	87
7/8CUR	1750	1750	1750	1313
3/4CUR	190	327	115	83
UR	2000	2000	2000	1725
1/8UR	250	250	250	188

TABLE 5-D-1

5-D-2 CTOL OPERATIONAL DATA

In order to compute operating costs for the CTOL aircraft, the following information was collected.

Aircraft	L-1011	747	727 -200	DC-9 Series 30
Maximum useable range (statute miles)	5290	8000	2300	1725
Cruise speed (miles per hour)	575	625	517	557
Horizontal distance traveled while climbing (miles)	70.0	92.5	52.5	60.0
Time to climb to cruise altitude (hours)	.233	.308	.175	.200
Normal gross weight of aircraft (pounds)	320000	710000	170000	98000
Empty weight of aircraft less engines (pounds)	166441	492280	85412	46365
Maximum number of passengers	300	490	178	115
Maximum speed (knots)	515	564	530	540
Number of engines	3	4	3	2
Thrust per engine (pounds)	111060	174000	43500	28000
Specific fuel comsumption at maximum power	.339	.350	.600	.590
Weight per engine (pounds)	6353	8430	3196	3096

TABLE 5-D-2

APPENDIX 6-A

AIR TRAFFIC CONTROL DELAY MODEL

This appendix contains the delay model flow diagram, flormulas and actual computer printout.

6-A-1 Nomenclature

RALT = Runway Altitude
HSTURNO = High Speed Turnoff Placement
PCT [I] = Percent of Aircraft Type I in Mix
RCF = Runway Correction Factor
CRLEN = Corrected Runway Length
RLEN = Runway Length
PAK = Equipment Package Identification
LAMS = Total Operations per Hour
LAML = Landings per Hour
LAMT = Takeoffs per Hour
AD = Air Delay
W = Ground Delay
T = Departure Followed by Departure Time
F = Departure Followed by Arrival Time
R = Runway Occupancy for Arrivals
C = Commitment Interval for Arrivals
A = Minimum Time Interval Between Consecutive Arrivals

6-A-2 Flow Diagram

The following is the flow diagram of the delay model.

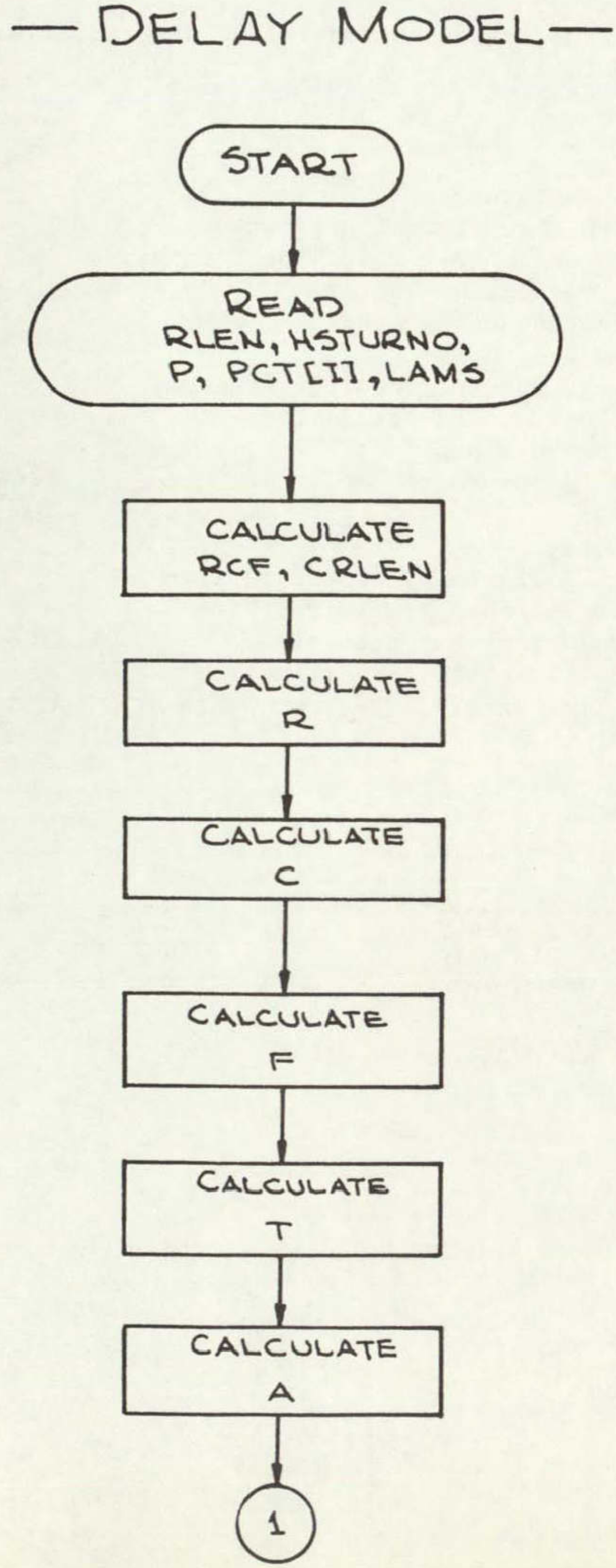


Figure 6-A-1

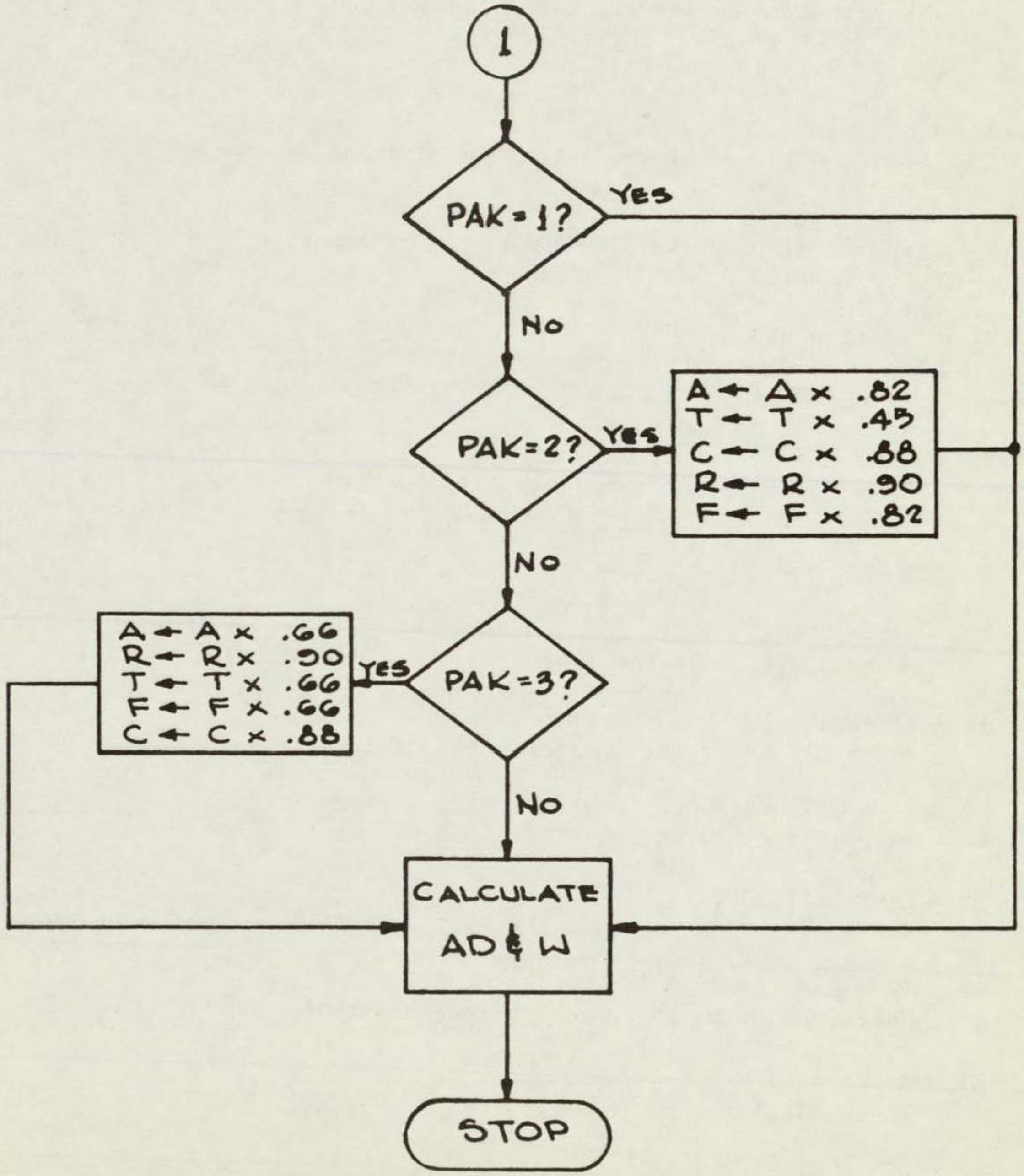


Figure 6-A-1 Continued

6-A-3 Delay Model Equations

A1 = 3600/LAML
Where: A1 is an intermediate step constant.

G1 = A1 - R - C1
Where: G1 is an intermediate step constant.
C1 = C

A2 = G1 ** 2 + A1 ** 2
Where: A2 ia an intermediate step constant.
G1 ** 2 $\rightarrow$ $(G1)^2$
A1 ** 2 $\rightarrow$ $(A1)^2$

G = 1/G1
Where: G is an intermediate step constant.

S1 = F1 - C1
Where: S1 is an intermediate step constant.
F1 = F

T1 = EXP (G * S1)
Where: T1 is an intermediate step constant.
EXP (G * S1) = $e^{(G \cdot S1)}$

T2 = EXP (-G * T)
Where: T3 is an intermediate step constant.

T3 = 1 - T2
Where: T3 is an intermediate step constant.

W21 = A1 * (T1 -1) - S1
Where: W21 is an intermediate step constant.

J1 = A1 * T1 * T3
Where: J1 is an intermediate step constant.

J2 = J1 * W21 + T1 * (A2 * T3/2 - A1 * T * T2)
Where: J2 is an intermediate step constant.

T4 = LAMT * J1/3600
Where: T4 is an intermediate step constant.

WO = J2 * LAMT/(3600 * (1 -T4))
Where: WO is an intermediate step constant.

W1 = A2/(2 * A1) - G1
Where: W1 is an intermediate step constant.

W = W21 + W1 + WO

AD = LAML * A22/(3600 * (2 * (2 - LAML * A11/3600)))
Where: A11 = Expacted value of A
A22 = Variance of A

6-A-4 Computer Printout

The following is the actual computer printout of the Delay Model written in the UNIVAC 1108 Algol computer language.

```
BEGIN

PROCEDURE      CALRCF(RALT,RCF);
   REAL        RALT;
   REAL ARRAY RCF;
   BEGIN
         RCF[1]=.03*RALT/1000+.99;
         RCF[2]=.19*RALT/6000+.99;
        RCF[3]=.22*RALT/6000+.99;
         RCF[4]=.24*RALT/6000+.99;
         RCF[5]=.16*RALT/3500+.99;

   END CALRCF;

PROCEDURE      CALER(RCF,RLEN,CRLEN,P,ER,HSTURNO);
   INTEGER     P;
   REAL        RLEN;
   REAL ARRAY CRLEN,ER,RCF,HSTURNO;
   BEGIN
        INTEGER I,N;
        REAL ARRAY  ERL,ERU,TURNOF[0:5];
         FOR I=1 STEP 1 UNTIL 5 DO CRLEN[I]=1.1*RCF[I]*RLEN;
         IF CRLEN[1] LEQ  5399 THEN GO TO ERR ELSE
    IF CRLEN[1] LEQ  6199  THEN BEGIN ERL[1]=2700;ERU[1]=4500;END   E SE
    IF CRLEN[1] LEQ  6999  THEN BEGIN ERL[1]=2900;ERU[1]=5000;END   E SE
    IF CRLEN[1] LEQ  7999  THEN BEGIN ERL[1]=3050;ERU[1]=5500;END   E SE
    IF CRLEN[1] LEQ  8999  THEN BEGIN ERL[1]=3200;ERU[1]=5900;END   E SE
    IF CRLEN[1] LEQ  9999  THEN BEGIN ERL[1]=3350;ERU[1]=6100;END   E SE
    IF CRLEN[1] LEQ  10999 THEN BEGIN ERL[1]=3500;ERU[1]=6400;END   E SE
    IF CRLEN[1] LEQ  11999 THEN BEGIN ERL[1]=3650;ERU[1]=6600;END   E SE
         BEGIN ERL[1]=3800;ERU[1]=6800;END;
    IF CRLEN[2] LEQ  5399  THEN BEGIN ERL[2]=1700;ERU[2]=3850;END   E SE
    IF CRLEN[2] LEQ  6199  THEN BEGIN ERL[2]=1800;ERU[2]=3900;END   E SE
    IF CRLEN[2] LEQ  6999  THEN BEGIN ERL[2]=1900;ERU[2]=4100;END   E SE
    IF CRLEN[2] LEQ  7999  THEN BEGIN ERL[2]=2000;ERU[2]=4300;END   E SE
    IF CRLEN[2] LEQ  8999  THEN BEGIN ERL[2]=2100;ERU[2]=4500 END   E SE
    IF CRLEN[2] LEQ  9999  THEN BEGIN ERL[2]=2200;ERU[2]=4650 END   E SE
    IF CRLEN[2] LEQ  10999 THEN BEGIN ERL[2]=2300;ERU[2]=4800 END   E SE
    IF CRLEN[2] LEQ  11999 THEN BEGIN ERL[2]=2400;ERU[2]=4950 END   E SE
         BEGIN ERL[2]=2500;ERU[2]=5100;END;
    IF CRLEN[3] LEQ  5399  THEN BEGIN ERL[3]=1100;ERU[3]=2700 END   E SE
    IF CRLEN[3] LEQ  6199  THEN BEGIN ERL[3]=1300;ERU[3]=2900 END   E SE
    IF CRLEN[3] LEQ  6999  THEN BEGIN ERL[3]=1450;ERU[3]=3100 END   E SE
    IF CRLEN[3] LEQ  7999  THEN BEGIN ERL[3]=1600;ERU[3]=3300 END   E SE
    IF CRLEN[3] LEQ  8999  THEN BEGIN ERL[3]=1700;ERU[3]=3500 END   E SE
    IF CRLEN[3] LEQ  9999  THEN BEGIN ERL[3]=1750;ERU[3]=3600 END   E SE
    IF CRLEN[3] LEQ  10999 THEN BEGIN ERL[3]=1750;ERU[3]=3650 END   E SE
    IF CRLEN[3] LEQ  11999 THEN BEGIN ERL[3]=1800;ERU[3]=3700 END   E SE
         BEGIN ERL[3]=1800;ERU[3]=3700;END;
    IF CRLEN[4] LEQ  5399  THEN BEGIN ERL[4]=850 ;ERU[4]=2400 END   E SE
    IF CRLEN[4] LEQ  6199  THEN BEGIN ERL[4]=950 ;ERU[4]=2500 END   E SE
    IF CRLEN[4] LEQ  6999  THEN BEGIN ERL[4]=1000;ERU[4]=2600 END   E SE
    IF CRLEN[4] LEQ  7999  THEN BEGIN ERL[4]=1050;ERU[4]=2900 END   E SE
    IF CRLEN[4] LEQ  8999  THEN BEGIN ERL[4]=1050;ERU[4]=3200 END   E SE
```

```
IF CRLEN[4] LEQ  9999  THEN BEGIN ERL[4]=1100;ERU[4]=3300 END  E SE
IF CRLEN[4] LEQ  10999 THEN BEGIN ERL[4]=1150;ERU[4]=3350 END  E SE
IF CRLEN[4] LEQ  11999 THEN BEGIN ERL[4]=1200;ERU[4]=3400 END  E SE
    BEGIN ERL[4]=1250;ERU[4]=3400;END;
IF CRLEN[5] LEQ  5399  THEN BEGIN ERL[5]=700 ;ERU[5]=1700 END  E SE
IF CRLEN[5] LEQ  6199  THEN BEGIN ERL[5]=700 ;ERU[5]=1850 END  E SE
IF CRLEN[5] LEQ  6999  THEN BEGIN ERL[5]=700 ;ERU[5]=2000 END  E SE
IF CRLEN[5] LEQ  7999  THEN BEGIN ERL[5]=750 ;ERU[5]=2150 END  E SE
IF CRLEN[5] LEQ  8999  THEN BEGIN ERL[5]=800 ;ERU[5]=2300 END  E SE
IF CRLEN[5] LEQ  9999  THEN BEGIN ERL[5]=900 ;ERU[5]=2400 END  E SE
IF CRLEN[5] LEQ  10999 THEN BEGIN ERL[5]=950 ;ERU[5]=2500 END  E SE
 IF CRLEN[5] LEQ 11999 THEN BEGIN ERL[5]=1000;ERU[5]=2600 END EL E
    BEGIN ERL[5]=1000;ERU[5]=2700;END;
    FOR I=1 STEP 1 UNTIL 5 DO TURNOF[I]=0;
    FOR I=1 STEP 1 UNTIL 5 DO     FOR N=1 STEP 1 UNTIL P DO
    IF HSTURNO[N] LEQ ERU[I] AND HSTURNO[N] GEQ ERL[I] THEN
    TURNOF[I]=TURNOF[I]+1;
 FOR I=1 STEP 1 UNTIL 5 DO IF TURNOF[I] EQL 0 THEN ER[I]=4 ELSE
IF TURNOF[I] EQL 1 THEN ER[I]=2 ELSE IF TURNOF[I] EQL 2 THEN ER[ ]=2
    ELSE ER[I]=1;          GO TO L1;
ERR:  WRITE('UNACEPT RUNWAY LENGTH');

L1:  END CALER;

PROCEDURE        CALRRATING(CRLEN,ER,PCT,RRATING);
   REAL ARRAY CRLEN,ER,PCT;      REAL RRATING;
   BEGIN
       INTEGER I,N;
       REAL ARRAY RR,IRR[0:5];
        IF CRLEN[1] LEQ 5399 THEN GO TO ERR ELSE
        IF CRLEN[1] LEQ 6199  THEN BEGIN
                    IF ER[1] EQL  1 THEN RR[1]=42 ELSE
                    IF ER[1] EQL  2 THEN RR[1]=46 ELSE
                    IF ER[1] EQL 3 THEN  RR[1]=50 ELSE RR[1]=59 EN
   ELSE IF CRLEN[1] LEQ  6999 THEN BEGIN
                    IF ER[1] EQL  1 THEN RR[1]=43 ELSE
                    IF ER[1] EQL  2 THEN RR[1]=47 ELSE
                    IF ER[1] EQL 3 THEN  RR[1]=51 ELSE RR[1]=59 EN
   ELSE IF CRLEN[1] LEQ  7999 THEN BEGIN
                    IF ER[1] EQL  1 THEN RR[1]=44 ELSE
                    IF ER[1] EQL  2 THEN RR[1]=47 ELSE
                    IF ER[1] EQL 3 THEN  RR[1]=52 ELSE RR[1]=60 EN
   ELSE IF CRLEN[1] LEQ  8999 THEN BEGIN
                    IF ER[1] EQL  1 THEN RR[1]=45 ELSE
                    IF ER[1] EQL  2 THEN RR[1]=48 ELSE
                    IF ER[1] EQL 3 THEN  RR[1]=53 ELSE RR[1]=61 EN
   ELSE IF CRLEN[1] LEQ  9999 THEN BEGIN
                    IF ER[1] EQL  1 THEN RR[1]=45 ELSE
                    IF ER[1] EQL  2 THEN RR[1]=49 ELSE
                    IF ER[1] EQL 3 THEN  RR[1]=54 ELSE RR[1]=64 EN
   ELSE IF CRLEN[1] LEQ  10999THEN BEGIN
                    IF ER[1] EQL  1 THEN RR[1]=45 ELSE
                    IF ER[1] EQL  2 THEN RR[1]=50 ELSE
                    IF ER[1] EQL 3 THEN  RR[1]=55 ELSE RR[1]=66 EN
   ELSE IF CRLEN[1] LEQ  11999THEN BEGIN
                    IF ER[1] EQL  1 THEN RR[1]=46 ELSE
                    IF ER[1] EQL  2 THEN RR[1]=52 ELSE
                    IF ER[1] EQL 3 THEN  RR[1]=58 ELSE RR[1]=68 EN
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```
      ELSE BEGIN
                     IF ER[1] EQL  1 THEN RR[1]=46 ELSE
                     IF ER[1] EQL  1 THEN RR[1]=53 ELSE
                     IF ER[1] EQL 3 THEN  RR[1]=60 ELSE RR[1]=70 EN ;
      IF CRLEN[2] LEQ 4299 THEN GO TO ERR ELSE
      IF CRLEN[2] LEQ 5399  THEN BEGIN
                     IF ER[2] EQL  1 THEN RR[2]=36 ELSE
                     IF ER[2] EQL  2 THEN RR[2]=38 ELSE
                     IF ER[2] EQL 3 THEN  RR[2]=40 ELSE RR[2]=48 EN
   ELSE IF CRLEN[2] LEQ  6199 THEN BEGIN
                     IF ER[2] EQL  1 THEN RR[2]=37 ELSE
                     IF ER[2] EQL  2 THEN RR[2]=39 ELSE
                     IF ER[2] EQL 3 THEN  RR[2]=41 ELSE RR[2]=51 EN
   ELSE IF CRLEN[2] LEQ  6999 THEN BEGIN
                     IF ER[2] EQL  1 THEN RR[2]=38 ELSE
                     IF ER[2] EQL  2 THEN RR[2]=40 ELSE
                     IF ER[2] EQL 3 THEN  RR[2]=42 ELSE RR[2]=53 EN
   ELSE IF CRLEN[2] LEQ  7999 THEN BEGIN
                     IF ER[2] EQL  1 THEN RR[2]=39 ELSE
                     IF ER[2] EQL  2 THEN RR[2]=41 ELSE
                     IF ER[2] EQL 3 THEN  RR[2]=43 ELSE RR[2]=55 EN
   ELSE IF CRLEN[2] LEQ  8999 THEN BEGIN
                     IF ER[2] EQL  1 THEN RR[2]=39 ELSE
                     IF ER[2] EQL  2 THEN RR[2]=42 ELSE
                     IF ER[2] EQL 3 THEN  RR[2]=45 ELSE RR[2]=57 EN
   ELSE IF CRLEN[2] LEQ  9999 THEN BEGIN
                     IF ER[2] EQL  1 THEN RR[2]=40 ELSE
                     IF ER[2] EQL  2 THEN RR[2]=44 ELSE
                     IF ER[2] EQL 3 THEN  RR[2]=49 ELSE RR[2]=59 EN
   ELSE IF CRLEN[2] LEQ  10999THEN BEGIN
                     IF ER[2] EQL  1 THEN RR[2]=40 ELSE
                     IF ER[2] EQL  2 THEN RR[2]=46 ELSE
                     IF ER[2] EQL 3 THEN  RR[2]=50 ELSE RR[2]=60 EN
   ELSE IF CRLEN[2] LEQ  11999THEN BEGIN
                     IF ER[2] EQL  1 THEN RR[2]=41 ELSE
                     IF ER[2] EQL  2 THEN RR[2]=47 ELSE
                     IF ER[2] EQL 3 THEN  RR[2]=51 ELSE RR[2]=62 EN
      ELSE BEGIN
                     IF ER[2] EQL  1 THEN RR[2]=41 ELSE
                     IF ER[2] EQL  2 THEN RR[2]=48 ELSE
                     IF ER[2] EQL 3 THEN  RR[2]=52 ELSE RR[2]=63 EN ;
      IF CRLEN[3] LEQ 2999 THEN GO TO ERR ELSE
      IF CRLEN[3] LEQ 4299  THEN BEGIN
                     IF ER[3] EQL  1 THEN RR[3]=30 ELSE
                     IF ER[3] EQL  2 THEN RR[3]=35 ELSE
                     IF ER[3] EQL 3 THEN  RR[3]=38 ELSE RR[3]=41 EN
   ELSE IF CRLEN[3] LEQ  5399 THEN BEGIN
                     IF ER[3] EQL  1 THEN RR[3]=32 ELSE
                     IF ER[3] EQL  2 THEN RR[3]=36 ELSE
                     IF ER[3] EQL 3 THEN  RR[3]=39 ELSE RR[3]=44 EN
   ELSE IF CRLEN[3] LEQ  6199 THEN BEGIN
                     IF ER[3] EQL  1 THEN RR[3]=33 ELSE
                     IF ER[3] EQL  2 THEN RR[3]=38 ELSE
                     IF ER[3] EQL 3 THEN  RR[3]=41 ELSE RR[3]=49 EN
   ELSE IF CRLEN[3] LEQ  6999 THEN BEGIN
                     IF ER[3] EQL  1 THEN RR[3]=34 ELSE
                     IF ER[3] EQL  2 THEN RR[3]=39 ELSE
                     IF ER[3] EQL 3 THEN  RR[3]=43 ELSE RR[3]=52 EN
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ELSE IF CRLEN[3] LEQ  7999 THEN BEGIN
                    IF ER[3] EQL  1 THEN RR[3]=35 ELSE
                    IF ER[3] EQL  2 THEN RR[3]=41 ELSE
                    IF ER[3] EQL 3 THEN  RR[3]=45 ELSE RR[3]=54 EN
ELSE IF CRLEN[3] LEQ  8999 THEN BEGIN
                    IF ER[3] EQL  1 THEN RR[3]=36 ELSE
                    IF ER[3] EQL  2 THEN RR[3]=42 ELSE
                    IF ER[3] EQL 3 THEN  RR[3]=47 ELSE RR[3]=55 EN
ELSE IF CRLEN[3] LEQ  9999 THEN BEGIN
                    IF ER[3] EQL  1 THEN RR[3]=37 ELSE
                    IF ER[3] EQL  2 THEN RR[3]=43 ELSE
                    IF ER[3] EQL 3 THEN  RR[3]=48 ELSE RR[3]=56 EN
ELSE IF CRLEN[3] LEQ  10999THEN BEGIN
                    IF ER[3] EQL  1 THEN RR[3]=38 ELSE
                    IF ER[3] EQL  2 THEN RR[3]=44 ELSE
                    IF ER[3] EQL 3 THEN  RR[3]=48 ELSE RR[3]=57 EN
ELSE IF CRLEN[3] LEQ  11999THEN BEGIN
                    IF ER[3] EQL  1 THEN RR[3]=39 ELSE
                    IF ER[3] EQL  2 THEN RR[3]=45 ELSE
                    IF ER[4] EQL 3 THEN  RR[3]=49 ELSE RR[3]=58 EN
    ELSE BEGIN
                    IF ER[3] EQL  1 THEN RR[3]=40 ELSE
                    IF ER[3] EQL  2 THEN RR[3]=46 ELSE
                    IF ER[3] EQL 3 THEN  RR[3]=49 ELSE RR[3]=59 EN ;
    IF CRLEN [4] LEQ 2999  THEN BEGIN
                    IF ER[4] EQL  1 THEN RR[4]=20 ELSE
                    IF ER[4] EQL  2 THEN RR[4]=27 ELSE
                    IF ER[4] EQL 3 THEN  RR[4]=33 ELSE RR[4]=39 EN
ELSE IF CRLEN[4] LEQ  4299 THEN BEGIN
                    IF ER[4] EQL  1 THEN RR[4]=22 ELSE
                    IF ER[4] EQL  2 THEN RR[4]=30 ELSE
                    IF ER[4] EQL 3 THEN  RR[4]=35 ELSE RR[4]=40 EN
ELSE IF CRLEN[4] LEQ  5399 THEN BEGIN
                    IF ER[4] EQL  1 THEN RR[4]=24 ELSE
                    IF ER[4] EQL  2 THEN RR[4]=31 ELSE
                    IF ER[4] EQL 3 THEN  RR[4]=37 ELSE RR[4]=41 EN
ELSE IF CRLEN[4] LEQ  6199 THEN BEGIN
                    IF ER[4] EQL  1 THEN RR[4]=25 ELSE
                    IF ER[4] EQL  2 THEN RR[4]=32 ELSE
                    IF ER[4] EQL 3 THEN  RR[4]=38 ELSE RR[4]=42 EN
ELSE IF CRLEN[4] LEQ  6999 THEN BEGIN
                    IF ER[4] EQL  1 THEN RR[4]=26 ELSE
                    IF ER[4] EQL  2 THEN RR[4]=33 ELSE
                    IF ER[4] EQL 3 THEN  RR[4]=38 ELSE RR[4]=43 EN
ELSE IF CRLEN[4] LEQ  7999 THEN BEGIN
                    IF ER[4] EQL  1 THEN RR[4]=27 ELSE
                    IF ER[4] EQL  2 THEN RR[4]=24 ELSE
                    IF ER[4] EQL 3 THEN  RR[4]=39 ELSE RR[4]=45 EN
ELSE IF CRLEN[4] LEQ  8999 THEN BEGIN
                    IF ER[4] EQL  1 THEN RR[4]=28 ELSE
                    IF ER[4] EQL  2 THEN RR[4]=35 ELSE
                    IF ER[4] EQL 3 THEN  RR[4]=41 ELSE RR[4]=47 EN
ELSE IF CRLEN[4] LEQ  9999 THEN BEGIN
                    IF ER[4] EQL  1 THEN RR[4]=30 ELSE
                    IF ER[4] EQL  2 THEN RR[4]=36 ELSE
                    IF ER[4] EQL 3 THEN  RR[4]=42 ELSE RR[4]=48 EN
ELSE IF CRLEN[4] LEQ  10999THEN BEGIN
                    IF ER[4] EQL  1 THEN RR[4]=32 ELSE
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                    IF ER[4] EQL  2 THEN RR[4]=37 ELSE
                    IF ER[4] EQL 3 THEN  RR[4]=44 ELSE RR[4]=49 EN
    ELSE IF CRLEN[4] LEQ  11999THEN BEGIN
                    IF ER[4] EQL  1 THEN RR[4]=34 ELSE
                    IF ER[4] EQL  2 THEN RR[4]=39 ELSE
                    IF ER[4] EQL 3 THEN  RR[4]=45 ELSE RR[4]=51 EN
       ELSE BEGIN
                    IF ER[4] EQL  1 THEN RR[4]=35 ELSE
                    IF ER[4] EQL  2 THEN RR[4]=41 ELSE
                    IF ER[4] EQL 3 THEN  RR[4]=46 ELSE RR[4]=53 EN ;
       IF CRLEN [5] LEQ 2999  THEN BEGIN
                    IF ER[5] EQL  1 THEN RR[5]=21 ELSE
                    IF ER[5] EQL  2 THEN RR[5]=28 ELSE
                    IF ER[5] EQL 3 THEN  RR[5]=33 ELSE RR[5]=39 EN
    ELSE IF CRLEN[5] LEQ  4299 THEN BEGIN
                    IF ER[5] EQL  1 THEN RR[5]=25 ELSE
                    IF ER[5] EQL  2 THEN RR[5]=29 ELSE
                    IF ER[5] EQL 3 THEN  RR[5]=34 ELSE RR[5]=40 EN
    ELSE IF CRLEN[5] LEQ  5399 THEN BEGIN
                    IF ER[5] EQL  1 THEN RR[5]=27 ELSE
                    IF ER[5] EQL  2 THEN RR[5]=30 ELSE
                    IF ER[5] EQL 3 THEN  RR[5]=35 ELSE RR[5]=42 EN
    ELSE IF CRLEN[5] LEQ  6199 THEN BEGIN
                    IF ER[5] EQL  1 THEN RR[5]=28 ELSE
                    IF ER[5] EQL  2 THEN RR[5]=31 ELSE
                    IF ER[5] EQL 3 THEN  RR[5]=36 ELSE RR[5]=44 EN
    ELSE IF CRLEN[5] LEQ  6999 THEN BEGIN
                    IF ER[5] EQL  1 THEN RR[5]=29 ELSE
                    IF ER[5] EQL  2 THEN RR[5]=32 ELSE
                    IF ER[5] EQL 3 THEN  RR[5]=37 ELSE RR[5]=46 EN
    ELSE IF CRLEN[5] LEQ  7999 THEN BEGIN
                    IF ER[5] EQL  1 THEN RR[5]=30 ELSE
                    IF ER[5] EQL  2 THEN RR[5]=33 ELSE
                    IF ER[5] EQL 3 THEN  RR[5]=38 ELSE RR[5]=48 EN
    ELSE IF CRLEN[5] LEQ  8999 THEN BEGIN
                    IF ER[5] EQL  1 THEN RR[5]=31 ELSE
                    IF ER[5] EQL  2 THEN RR[5]=34 ELSE
                    IF ER[5] EQL 3 THEN  RR[5]=39 ELSE RR[5]=50 EN
    ELSE IF CRLEN[5] LEQ  9999 THEN BEGIN
                    IF ER[5] EQL  1 THEN RR[5]=32 ELSE
                    IF ER[5] EQL  2 THEN RR[5]=36 ELSE
                    IF ER[5] EQL 3 THEN  RR[5]=40 ELSE RR[5]=52 EN
    ELSE IF CRLEN[5] LEQ  10999THEN BEGIN
                    IF ER[5] EQL  1 THEN RR[5]=33 ELSE
                    IF ER[5] EQL  2 THEN RR[5]=37 ELSE
                    IF ER[5] EQL 3 THEN  RR[5]=41 ELSE RR[5]=53 EN
    ELSE IF CRLEN[5] LEQ  11999THEN BEGIN
                    IF ER[5] EQL  1 THEN RR[5]=34 ELSE
                    IF ER[5] EQL  2 THEN RR[5]=39 ELSE
                    IF ER[5] EQL 3 THEN  RR[5]=43 ELSE RR[5]=54 EN
       ELSE BEGIN
                    IF ER[5] EQL  1 THEN RR[5]=35 ELSE
                    IF ER[5] EQL  2 THEN RR[5]=40 ELSE
                    IF ER[5] EQL 3 THEN  RR[5]=45 ELSE RR[5]=55 EN ;
       FOR I=1 STEP 1 UNTIL 5 DO IRR[I]=RR[I]*PCT[I];
       RRATING=IRR[1]+IRR[2]+IRR[3]+IRR[4]+IRR[5];    GO TO L2;
ERR:  WRITE ('UNACCEPT RUNWAY LENGTH');
```

```
L2:  END CALRRATING;

PROCEDURE       CALR(LAML,RRATING,R,PAK);    INTEGER     PAK;
   REAL         LAML,RRATING,R;
   BEGIN
        IF LAML LEQ 20 THEN R=RRATING*(1.216-.0108*LAML) ELSE
        IF LAML LEQ 30 THEN R=RRATING*(1.1-.005*LAML) ELSE
        IF LAML LEQ 40 THEN R=RRATING*(1.0325-.00275*LAML) ELSE
    BEGIN IF RRATING GEQ 65 THEN R=RRATING*.925 ELSE R=RRATING*.927 END;
IF PAK EQL 2  THEN  R= R*.90 ELSE IF PAK EQL 3  THEN  R= R*.90 ELSE
IF PAK EQL 64 THEN  R= R*.95 ELSE IF PAK EQL 65 THEN  R= R*.90 ELSE
IF PAK EQL 66 THEN  R= R*.85 ELSE IF PAK EQL 67 THEN  R= R*.80 ELSE
IF PAK EQL 68 THEN  R= R*.75 ELSE IF PAK EQL 69 THEN  R= R*.70 ELSE
IF PAK EQL 70 THEN  R= R*.65 ELSE IF PAK EQL 71 THEN  R= R*.60 ELSE
IF PAK EQL 72 THEN  R= R*.55 ELSE IF PAK EQL 73 THEN  R= R*.50 ELSE
IF PAK EQL 74 THEN  R= R*.45 ELSE IF PAK EQL 75 THEN  R= R*.40 ELSE
IF PAK EQL 76 THEN  R= R*.35 ELSE IF PAK EQL 77 THEN  R= R*.30 ELSE
IF PAK EQL 78 THEN  R= R*.25 ELSE IF PAK EQL 79 THEN  R= R*.20 ELSE
IF PAK EQL 80 THEN  R= R*.15 ELSE IF PAK EQL 81 THEN  R= R*.10 ELSE
IF PAK EQL 82 THEN  R= R*.05;

   END;

PROCEDURE      CALC1(PCT,C1,PAK);
         INTEGER PAK;
   REAL          C1;
   REAL ARRAY  PCT;
   BEGIN
         REAL ARRAY C[0:5];
         C[1]=28;C[2]=19;C[3]=16;C[4]=14;C[5]=10;
        C1=C[1]*PCT[1]+C[2]*PCT[2]+C[3]*PCT[3]+C[4]*PCT[4]+C[5]*PCT[5];
IF PAK EQL 2  THEN C1=C1*.88 ELSE IF PAK EQL 3  THEN C1=C1*.88 ELSE
IF PAK EQL 24 THEN C1=C1*.95 ELSE IF PAK EQL 25 THEN C1=C1*.90 ELSE
IF PAK EQL 26 THEN C1=C1*.85 ELSE IF PAK EQL 27 THEN C1=C1*.80 ELSE
IF PAK EQL 28 THEN C1=C1*.75 ELSE IF PAK EQL 29 THEN C1=C1*.70 ELSE
IF PAK EQL 30 THEN C1=C1*.65 ELSE IF PAK EQL 31 THEN C1=C1*.60 ELSE
IF PAK EQL 32 THEN C1=C1*.55 ELSE IF PAK EQL 33 THEN C1=C1*.50 ELSE
IF PAK EQL 34 THEN C1=C1*.45 ELSE IF PAK EQL 35 THEN C1=C1*.40 ELSE
IF PAK EQL 36 THEN C1=C1*.35 ELSE IF PAK EQL 37 THEN C1=C1*.30 ELSE
IF PAK EQL 38 THEN C1=C1*.25 ELSE IF PAK EQL 39 THEN C1=C1*.20 ELSE
IF PAK EQL 40 THEN C1=C1*.15 ELSE IF PAK EQL 41 THEN C1=C1*.10 ELSE
IF PAK EQL 42 THEN C1=C1*.05;

   END;

PROCEDURE      CALF1(PCT,F1,PAK);       INTEGER   PAK;
   REAL          F1;
   REAL ARRAY  PCT;
   BEGIN
         INTEGER I,N;
         REAL ARRAY F,FF[0:5,0:5];
         F[1,1]=56;F[1,2]=74;F[1,3]=83;F[1,4]=66;F[1,5]=86;
         F[2,1]=56;F[2,2]=43;F[2,3]=50;F[2,4]=66;F[2,5]=86;
         F[3,1]=56;F[3,2]=43;F[3,3]=50;F[3,4]=66;F[3,5]=86;
         F[4,1]=56;F[4,2]=43;F[4,3]=50;F[4,4]=66;F[4,5]=86;
         F[5,1]=56;F[5,2]=43;F[5,3]=50;F[5,4]=66;F[5,5]=86;
         FF[0,0]=0;FF[0,1]=0;FF[0,2]=0;FF[0,3]=0;FF[0,4]=0;
         FOR I=1 STEP 1 UNTIL 5 DO FOR N=1 STEP 1 UNTIL 5 DO
```

```
        FF[I,N]=PCT[I]*PCT[N]*F[I,N];
         F1=FF[1,1]+FF[1,2]+FF[1,3]+FF[1,4]+FF[1,5]+
            FF[2,1]+FF[2,2]+FF[2,3]+FF[2,4]+FF[2,5]+
            FF[3,1]+FF[3,2]+FF[3,3]+FF[3,4]+FF[3,5]+
            FF[4,1]+FF[4,2]+FF[4,3]+FF[4,4]+FF[4,5]+
         FF[5,1]+FF[5,2]+FF[5,3]+FF[5,4]+FF[5,5];
IF PAK EQL 2  THEN F1=F1*.82 ELSE IF PAK EQL 3  THEN F1=F1*.66 ELSE
IF PAK EQL 44 THEN F1=F1*.95 ELSE IF PAK EQL 45 THEN F1=F1*.90 ELSE
IF PAK EQL 46 THEN F1=F1*.85 ELSE IF PAK EQL 47 THEN F1=F1*.80 ELSE
IF PAK EQL 48 THEN F1=F1*.75 ELSE IF PAK EQL 49 THEN F1=F1*.70 ELSE
IF PAK EQL 50 THEN F1=F1*.65 ELSE IF PAK EQL 51 THEN F1=F1*.60 ELSE
IF PAK EQL 52 THEN F1=F1*.55 ELSE IF PAK EQL 53 THEN F1=F1*.50 ELSE
IF PAK EQL 54 THEN F1=F1*.45 ELSE IF PAK EQL 55 THEN F1=F1*.40 ELSE
IF PAK EQL 56 THEN F1=F1*.35 ELSE IF PAK EQL 57 THEN F1=F1*.30 ELSE
IF PAK EQL 58 THEN F1=F1*.25 ELSE IF PAK EQL 59 THEN F1=F1*.20 ELSE
IF PAK EQL 60 THEN F1=F1*.15 ELSE IF PAK EQL 61 THEN F1=F1*.10 ELSE
IF PAK EQL 62 THEN F1=F1*.05;

   END;

PROCEDURE       CALT(LAMS,PCT,T,PAK);       INTEGER   PAK;
   REAL         LAMS,T;
   REAL ARRAY   PCT;
   BEGIN
         REAL ARRAY TT,TAM[0:5,0:5];
         INTEGER  I,N;
     IF LAMS LEQ  10 THEN TAM[1,1]=94.2  ELSE
     IF LAMS LEQ  20 THEN TAM[1,1]=90.0  ELSE
     IF LAMS LEQ  30 THEN TAM[1,1]=87.5  ELSE
     IF LAMS LEQ  40 THEN TAM[1,1]=86.0  ELSE
     IF LAMS LEQ  50 THEN TAM[1,1]=86.0  ELSE
         TAM[1,1]=86.0;
     IF LAMS LEQ  10 THEN TAM[1,2]=85.2  ELSE
     IF LAMS LEQ  20 THEN TAM[1,2]=81.2  ELSE
     IF LAMS LEQ  30 THEN TAM[1,2]=79    ELSE
     IF LAMS LEQ  40 THEN TAM[1,2]=77    ELSE
     IF LAMS LEQ  50 THEN TAM[1,2]=77    ELSE
         TAM[1,2]=77.0;
         IF LAMS LEQ 10 THEN TAM[1,3]=100.8 ELSE
     IF LAMS LEQ  20 THEN TAM[1,3]=83.2  ELSE
     IF LAMS LEQ  30 THEN TAM[1,3]=74.8  ELSE
     IF LAMS LEQ  40 THEN TAM[1,3]=69.4  ELSE
     IF LAMS LEQ  50 THEN TAM[1,3]=67    ELSE
         TAM[1,3]=67.0;
     IF LAMS LEQ  10 THEN TAM[1,4]=96.8  ELSE
     IF LAMS LEQ  20 THEN TAM[1,4]=85.5  ELSE
     IF LAMS LEQ  30 THEN TAM[1,4]=78.5  ELSE
     IF LAMS LEQ  40 THEN TAM[1,4]=73.5  ELSE
     IF LAMS LEQ  50 THEN TAM[1,4]=70.4  ELSE
         TAM[1,4]=67.5;
     IF LAMS LEQ  10 THEN TAM[1,5]=96.8  ELSE
     IF LAMS LEQ  20 THEN TAM[1,5]=85.5  ELSE
     IF LAMS LEQ  30 THEN TAM[1,5]=78.5  ELSE
     IF LAMS LEQ  40 THEN TAM[1,5]=73.5  ELSE
     IF LAMS LEQ  50 THEN TAM[1,5]=70.4  ELSE
         TAM[1,5]=67.5;
     IF LAMS LEQ  10 THEN TAM[2,1]=114.5 ELSE
     IF LAMS LEQ  20 THEN TAM[2,1]=107   ELSE
```

```
IF LAMS LEQ  30 THEN TAM[2,1]=102.5 ELSE
     TAM[2,1]=100.0;
IF LAMS LEQ  10 THEN TAM[2,2]=110   ELSE
IF LAMS LEQ  20 THEN TAM[2,2]=89    ELSE
IF LAMS LEQ  30 THEN TAM[2,2]=78.5  ELSE
IF LAMS LEQ  40 THEN TAM[2,2]=72    ELSE
     TAM[2,2]=69.0;
IF LAMS LEQ  10 THEN TAM[2,3]=79    ELSE
IF LAMS LEQ  20 THEN TAM[2,3]=69.4  ELSE
IF LAMS LEQ  30 THEN TAM[2,3]=65.2  ELSE
IF LAMS LEQ  40 THEN TAM[2,3]=62    ELSE
IF LAMS LEQ  50 THEN TAM[2,3]=59.8  ELSE
     TAM[2,3]=59.0;
IF LAMS LEQ  10 THEN TAM[2,4]=108.3 ELSE
IF LAMS LEQ   20 THEN TAM[2,4]=77.5  ELSE
IF LAMS LEQ  30 THEN TAM[2,4]=63.8  ELSE
IF LAMS LEQ  40 THEN TAM[2,4]=55.8  ELSE
IF LAMS LEQ  50 THEN TAM[2,4]=49.5  ELSE
     TAM[2,4]=45.5;
     TAM[2,5]=TAM[2,4];
IF LAMS LEQ  10 THEN TAM[3,1]=145.5 ELSE
IF LAMS LEQ  20 THEN TAM[3,1]=126.4 ELSE
IF LAMS LEQ  30 THEN TAM[3,1]=117.3 ELSE
     TAM[3,1]=111.0;
IF LAMS LEQ  10 THEN TAM[3,2]=129   ELSE
IF LAMS LEQ  20 THEN TAM[3,2]=113.6 ELSE
IF LAMS LEQ  30 THEN TAM[3,2]=106   ELSE
     TAM[3,2]=101.0;
IF LAMS LEQ  10 THEN TAM[3,3]=97    ELSE
IF LAMS LEQ  20 THEN TAM[3,3]=84.5  ELSE
IF LAMS LEQ  30 THEN TAM[3,3]=78    ELSE
IF LAMS LEQ  40 THEN TAM[3,3]=74    ELSE
     TAM[3,3]=73.0;
IF LAMS LEQ  10 THEN TAM[3,4]=103.8 ELSE
IF LAMS LEQ  20 THEN TAM[3,4]=84.2  ELSE
IF LAMS LEQ  30 THEN TAM[3,4]=75.5  ELSE
IF LAMS LEQ  40 THEN TAM[3,4]=69.5  ELSE
     TAM[3,4]=67.0;
     TAM[3,5]=TAM[3,4];
IF LAMS LEQ  10 THEN TAM[4,1]=157   ELSE
IF LAMS LEQ  20 THEN TAM[4,1]=150.2 ELSE
IF LAMS LEQ  30 THEN TAM[4,1]=146   ELSE
     TAM[4,1]=143.0;
IF LAMS LEQ  10 THEN TAM[4,2]=143   ELSE
IF LAMS LEQ  20 THEN TAM[4,2]=136   ELSE
IF LAMS LEQ  30 THEN TAM[4,2]=131.5 ELSE
     TAM[4,2]=143.0;
IF LAMS LEQ  10 THEN TAM[4,3]=133.8 ELSE
     TAM[4,3]=100.0;
IF LAMS LEQ  10 THEN TAM[4,4]=114.5 ELSE
IF LAMS LEQ  20 THEN TAM[4,4]=91.2  ELSE
IF LAMS LEQ  30 THEN TAM[4,4]=81.8  ELSE
IF LAMS LEQ  40 THEN TAM[4,4]=76    ELSE
     TAM[4,4]=75.0;
     TAM[4,5]=TAM[4,4];
     TAM[5,1]=TAM[4,1];TAM[5,2]=TAM[4,2];TAM[5,3]=TAM[4,3];
     TAM[5,4]=TAM[4,4];TAM[5,5]=TAM[4,5];
     TT[0,1]=0;TT[0,2]=0;TT[0,3]=0;TT[0,4]=0;    TT[0,0]=0;
```

```
        FOR I=1 STEP 1 UNTIL 5 DO FOR N=1 STEP 1 UNTIL 5 DO
        TT[I,N]=PCT[I]*PCT[N]*TAM[I,N];
        T=TT[1,1]+TT[1,2]+TT[1,3]+TT[1,4]+TT[1,5]+
          TT[2,1]+TT[2,2]+TT[2,3]+TT[2,4]+TT[2,5]+
          TT[3,1]+TT[3,2]+TT[3,3]+TT[3,4]+TT[3,5]+
          TT[4,1]+TT[4,2]+TT[4,3]+TT[4,4]+TT[4,5]+
          TT[5,1]+TT[5,2]+TT[5,3]+TT[5,4]+TT[5,5];
IF PAK EQL 2  THEN  T= T*.45 ELSE IF PAK EQL 3  THEN  T= T*.45 ELSE
IF PAK EQL 4  THEN  T= T*.95 ELSE IF PAK EQL 5  THEN  T= T*.90 ELSE
IF PAK EQL 6  THEN  T= T*.85 ELSE IF PAK EQL 7  THEN  T= T*.80 ELSE
IF PAK EQL 8  THEN  T= T*.75 ELSE IF PAK EQL 9  THEN  T= T*.70 ELSE
IF PAK EQL 10 THEN  T= T*.65 ELSE IF PAK EQL 11 THEN  T= T*.60 ELSE
IF PAK EQL 12 THEN  T= T*.55 ELSE IF PAK EQL 13 THEN  T= T*.50 ELSE
IF PAK EQL 14 THEN  T= T*.45 ELSE IF PAK EQL 15 THEN  T= T*.40 ELSE
IF PAK EQL 16 THEN  T= T*.35 ELSE IF PAK EQL 17 THEN  T= T*.30 ELSE
IF PAK EQL 18 THEN  T= T*.25 ELSE IF PAK EQL 19 THEN  T= T*.20 ELSE
IF PAK EQL 20 THEN  T= T*.15 ELSE IF PAK EQL 21 THEN  T= T*.10 ELSE
IF PAK EQL 22 THEN  T= T*.05;

    END;

          PROCEDURE  CALA(LAML,PCT,A11,A22,PAK);
               INTEGER PAK;
               REAL LAML,A11,A22;
               REAL ARRAY PCT;
         BEGIN
     INTEGER  I,J,K;
     REAL ARRAY  AAM[0:5,0:5],TERM[0:25],A[0:5,0:5];
    IF LAML LEQ 10   THEN AAM[1,1]=179.0 ELSE
    IF LAML LEQ 20   THEN AAM[1,1]=172.0 ELSE
    IF LAML LEQ 30   THEN AAM[1,1]=168.0 ELSE
    IF LAML LEQ 40   THEN AAM[1,1]=165.0 ELSE
    IF LAML LEQ 50   THEN AAM[1,1]=164.0 ELSE
    AAM[1,1]=162.0;
    IF LAML LEQ 10   THEN AAM[1,2]=190.0 ELSE
    IF LAML LEQ 20   THEN AAM[1,2]=184.0 ELSE
    IF LAML LEQ 30   THEN AAM[1,2]=181.0 ELSE
    IF LAML LEQ 40   THEN AAM[1,2]=179.0 ELSE
    IF LAML LEQ 50   THEN AAM[1,2]=177.0 ELSE
    AAM[1,2]=176.0;
    IF LAML LEQ 10   THEN AAM[1,3]=220.0 ELSE
    IF LAML LEQ 20   THEN AAM[1,3]=200.0 ELSE
    IF LAML LEQ 30   THEN AAM[1,3]=189.0 ELSE
    IF LAML LEQ 40   THEN AAM[1,3]=182.0 ELSE
    IF LAML LEQ 50   THEN AAM[1,3]=178.0 ELSE
    AAM[1,3]=174.0;
    IF LAML LEQ 10   THEN AAM[1,4]=226.0 ELSE
    IF LAML LEQ 20   THEN AAM[1,4]=212.0 ELSE
    IF LAML LEQ 30   THEN AAM[1,4]=204.0 ELSE
    IF LAML LEQ 40   THEN AAM[1,4]=199.0 ELSE
    IF LAML LEQ 50   THEN AAM[1,4]=196.0 ELSE
    AAM[1,4]=193.0;
    IF LAML LEQ 10   THEN AAM[2,1]=136.0 ELSE
    IF LAML LEQ 20   THEN AAM[2,1]=123.0 ELSE
    IF LAML LEQ 30   THEN AAM[2,1]=116.0 ELSE
    IF LAML LEQ 40   THEN AAM[2,1]=111.0 ELSE
    IF LAML LEQ 50   THEN AAM[2,1]=108.0 ELSE
    AAM[2,1]=106.0;
```

```
IF LAML LEQ 10  THEN AAM[2,2]=176.0 ELSE
IF LAML LEQ 20  THEN AAM[2,2]=140.0 ELSE
IF LAML LEQ 30  THEN AAM[2,2]=125.0 ELSE
IF LAML LEQ 40  THEN AAM[2,2]=116.0 ELSE
IF LAML LEQ 50  THEN AAM[2,2]=111.0 ELSE
AAM[2,2]=111.0;
IF LAML LEQ 10  THEN AAM[2,3]=161.0 ELSE
IF LAML LEQ 20  THEN AAM[2,3]=133.0 ELSE
IF LAML LEQ 30  THEN AAM[2,3]=120.0 ELSE
IF LAML LEQ 40  THEN AAM[2,3]=111.0 ELSE
IF LAML LEQ 50  THEN AAM[2,3]=107.0 ELSE
AAM[2,3]=103.0;
IF LAML LEQ 10  THEN AAM[2,4]=233.0 ELSE
IF LAML LEQ 20  THEN AAM[2,4]=193.0 ELSE
IF LAML LEQ 30  THEN AAM[2,4]=176.0 ELSE
IF LAML LEQ 40  THEN AAM[2,4]=166.0 ELSE
IF LAML LEQ 50  THEN AAM[2,4]=161.0 ELSE
AAM[2,4]=161.0;
IF LAML LEQ 10  THEN AAM[3,1]=144.0 ELSE
IF LAML LEQ 20  THEN AAM[3,1]=129.0 ELSE
IF LAML LEQ 30  THEN AAM[3,1]=122.0 ELSE
IF LAML LEQ 40  THEN AAM[3,1]=117.0 ELSE
IF LAML LEQ 50  THEN AAM[3,1]=113.0 ELSE
AAM[3,1]=110.0;
IF LAML LEQ 10  THEN AAM[3,2]=121.0 ELSE
IF LAML LEQ 20  THEN AAM[3,2]=108.0 ELSE
IF LAML LEQ 30  THEN AAM[3,2]=102.0 ELSE
IF LAML LEQ 40  THEN AAM[3,2]=98.0  ELSE
IF LAML LEQ 50  THEN AAM[3,2]=96.0  ELSE
AAM[3,2]=93.0;
IF LAML LEQ 10  THEN AAM[3,3]=160.0 ELSE
IF LAML LEQ 20  THEN AAM[3,3]=138.0 ELSE
IF LAML LEQ 30  THEN AAM[3,3]=129.0 ELSE
IF LAML LEQ 40  THEN AAM[3,3]=122.0 ELSE
IF LAML LEQ 50  THEN AAM[3,3]=118.0 ELSE
AAM[3,3]=115.0;
IF LAML LEQ 10  THEN AAM[3,4]=184.0 ELSE
IF LAML LEQ 20  THEN AAM[3,4]=161.0 ELSE
IF LAML LEQ 30  THEN AAM[3,4]=151.0 ELSE
IF LAML LEQ 40  THEN AAM[3,4]=145.0 ELSE
IF LAML LEQ 50  THEN AAM[3,4]=141.0 ELSE
AAM[3,4]=141.0;
IF LAML LEQ 10  THEN AAM[4,1]=136.0 ELSE
IF LAML LEQ 20  THEN AAM[4,1]=112.0 ELSE
IF LAML LEQ 30  THEN AAM[4,1]=101.0 ELSE
IF LAML LEQ 40  THEN AAM[4,1]=97.0  ELSE
IF LAML LEQ 50  THEN AAM[4,1]=97.0  ELSE
AAM[4,1]=97.0;
IF LAML LEQ 10  THEN AAM[4,2]=139.0 ELSE
IF LAML LEQ 20  THEN AAM[4,2]=122.0 ELSE
IF LAML LEQ 30  THEN AAM[4,2]=114.0 ELSE
IF LAML LEQ 40  THEN AAM[4,2]=109.0 ELSE
IF LAML LEQ 50  THEN AAM[4,2]=108.0 ELSE
AAM[4,2]=108.0;
IF LAML LEQ 10  THEN AAM[4,3]=149.0 ELSE
IF LAML LEQ 20  THEN AAM[4,3]=130.0 ELSE
IF LAML LEQ 30  THEN AAM[4,3]=121.0 ELSE
IF LAML LEQ 40  THEN AAM[4,3]=116.0 ELSE
```

```
    IF LAML LEQ 50  THEN AAM[4,3]=115.0 ELSE
    AAM[4,3]=115.0;
    IF LAML LEQ 10  THEN AAM[4,4]=179.0 ELSE
    IF LAML LEQ 20  THEN AAM[4,4]=148.0 ELSE
    IF LAML LEQ 30  THEN AAM[4,4]=136.0 ELSE
    IF LAML LEQ 40  THEN AAM[4,4]=128.0 ELSE
    IF LAML LEQ 50  THEN AAM[4,4]=124.0 ELSE
    AAM[4,4]=120.0;
     AAM[1,5]=AAM[1,4];  AAM[2,5]=AAM[2,4];  AAM[3,5]=AAM[3,4];
    AAM[4,5]=AAM[4,4];  AAM[5,1]=AAM[4,1];  AAM[5,2]=AAM[4,2];
    AAM[5,3]=AAM[4,3];  AAM[5,4]=AAM[4,4];  AAM[5,5]=AAM[4,4];
    K=0;
     FOR J=1 STEP 1 UNTIL 5 DO FOR I=1 STEP 1 UNTIL 5 DO BEGIN
A[I,J]=AAM[I,J];
IF PAK EQL 2    THEN A[I,J]=A[I,J]*.88 ELSE
IF PAK EQL 3    THEN A[I,J]=A[I,J]*.88 ELSE
IF PAK EQL 84   THEN A[I,J]=A[I,J]*.95 ELSE
IF PAK EQL 85   THEN A[I,J]=A[I,J]*.90 ELSE
IF PAK EQL 86   THEN A[I,J]=A[I,J]*.85 ELSE
IF PAK EQL 87   THEN A[I,J]=A[I,J]*.80 ELSE
IF PAK EQL 88   THEN A[I,J]=A[I,J]*.75 ELSE
IF PAK EQL 89   THEN A[I,J]=A[I,J]*.70 ELSE
IF PAK EQL 90   THEN A[I,J]=A[I,J]*.65 ELSE
IF PAK EQL 91   THEN A[I,J]=A[I,J]*.60 ELSE
IF PAK EQL 92   THEN A[I,J]=A[I,J]*.55 ELSE
IF PAK EQL 93   THEN A[I,J]=A[I,J]*.50 ELSE
IF PAK EQL 94   THEN A[I,J]=A[I,J]*.45 ELSE
IF PAK EQL 95   THEN A[I,J]=A[I,J]*.40 ELSE
IF PAK EQL 96   THEN A[I,J]=A[I,J]*.35 ELSE
IF PAK EQL 97   THEN A[I,J]=A[I,J]*.30 ELSE
IF PAK EQL 98   THEN A[I,J]=A[I,J]*.25 ELSE
IF PAK EQL 99   THEN A[I,J]=A[I,J]*.20 ELSE
IF PAK EQL 100  THEN A[I,J]=A[I,J]*.15 ELSE
IF PAK EQL 101  THEN A[I,J]=A[I,J]*.10 ELSE
IF PAK EQL 102  THEN A[I,J]=A[I,J]*.05;
K=K+1;  TERM[K]=PCT[I]*PCT[J]*AAM[I,J];
    END;      A11=0;
     FOR K=1 STEP 1 UNTIL 25 DO A11=A11+TERM[K];
     K=0;
     FOR J=1 STEP 1 UNTIL 5 DO FOR I=1 STEP 1 UNTIL 5 DO BEGIN
K=K+1; TERM[K]= PCT[I]*PCT[J]*(AAM[I,J]**2);       END; A22=0;
    FOR K=1 STEP 1 UNTIL 25 DO A22=A22+TERM[K];

END  CALA;

PROCEDURE      DELAY(LAML,A,B,C,D,E,W,AD,PAK);
REAL LAML,W,AD,              A,B,C,D,E;  INTEGER  PAK;
BEGIN
REAL      A1,A2,G,G1,S1,T,T1,T2,T3,T4,J1,J2,W0,W1,W2,  W21,R,F1,C1,RLEN,
          RALT,RRATING,A11, LAMT,LAMS,  A22;
REAL ARRAY  RCF,CRLEN,ER,PCT[0:5],HSTURNO[0:10],F[0:25,0:25],
          FF[0:5,0:5];
INTEGER  P;
         RLEN=9500;
            P=3;HSTURNO[1]=3000;HSTURNO[2]=4500;HSTURNO[3]=6200;
              RALT=4800;
            PCT[1]=A;PCT[2]=B;PCT[3]=C;PCT[4]=D;PCT[5]=E;
            LAMS=2*LAML;   LAMT=LAML;
```

```
        CALRCF(RALT,RCF);
    CALA(LAML,PCT,A11,A22,PAK);
       CALER(RCF,RLEN,CRLEN,P,ER,HSTURNO);
       CALRRATING(CRLEN,ER,PCT,RRATING);
        CALR(LAML,RRATING,R,PAK);
             CALC1(PCT,C1,PAK);
       CALF1(PCT,F1,PAK);
       CALT(LAMS,PCT,T,PAK);
        A1=3600/LAML;
        G1=A1-R-C1;
        A2=G1**2+A1**2;
        G=1/G1;
        S1=F1-C1;
        T1=EXP(G*S1);
        T2=EXP(-G*T);
        T3=1-T2;
        W21=A1*(T1-1)-S1;
        J1=A1*T1*T3;
        J2=J1*W21+T1*(A2*T3/2-A1*T*T2);
        T4=LAMT*J1/3600;
        W0=J2*LAMT/(3600*(1-T4));
        W1=A2/(2*A1)-G1;
        W=W21+W1+W0;
    AD=LAML*A22/(3600*(2*(1-LAML*A11/3600)));

END DELAY;
REAL   J1,J2,T4,W0,LAMT,F1,W1,R,C1,T,A1,G1,A2,G,S1,T1,T2,W21,LAML,A,. ,C,
D,E,AD,W,A11,A22;  INTEGER PAK;
FORMAT F7(X20,'AIR AND GROUND DELAY',A1.1);
FORMAT F2(X9,,OPNS/HR',X5,'AIRDELAY',X9,'GROUNDDELAY',A1.1);
FORMAT
    F3(X20,'A=0.0',X2,'B=0.0',X2,'C=0.0',X2,'D=1.0',X2,'E=0.0',A1.1)
FORMAT
    F4(X20,'A=0.6',X2,'B=0.0',X2,'C=0.2',X2,'D=0.2',X2,'E=0.0',A1.1)
FORMAT
    F5(X20,'A=0.2',X2,'B=0.0',X2,'C=0.6',X2,'D=0.2',X2,'E=0.0',A1.1)
FORMAT  F6(X9,D7.2,X5,D7.2,X9,D7.2,A1);
        FOR PAK=1 STEP 1 UNTIL 3 DO BEGIN
WRITE('PAK=',PAK);
     A=0.0;  B=0.0;  C=0.0;  D=1.0;  E=0.0;
    WRITE (F7); WRITE (F3);  WRITE (F2);
    FOR LAML=5 STEP 1 UNTIL 19 DO
    BEGIN
         DELAY(LAML,A,B,C,D,E,W,AD,PAK);
         WRITE (F6,LAML,AD,W);       END;
      A=0.6;  B=0.0;  C=0.4;  D=0.0;  E=0.0;
    WRITE (F7); WRITE (F4);  WRITE (F2);
    FOR LAML=5 STEP 1 UNTIL 19 DO
    BEGIN
         DELAY(LAML,A,B,C,D,E,W,AD,PAK);
         WRITE (F6,LAML,AD,W);       END;
      A=0.2;  B=0.0;  C=0.6;  D=0.2;  E=0.0;
    WRITE (F7); WRITE (F5);  WRITE (F2);
    FOR LAML=5 STEP 1 UNTIL 19 DO
    BEGIN
         DELAY(LAML,A,B,C,D,E,W,AD,PAK);
         WRITE (F6,LAML,AD,W);       END;
END;
```

```
            A=.10; B=.45; C=.12; D=.13; E=.20;
FOR LAML=5 STEP 1 UNTIL 19 DO
FOR PAK=1 STEP 1 UNTIL 102 DO BEGIN
     WRITE (F7); WRITE (F5); WRITE (F2);
          DELAY(LAML,A,B,C,D,E,W,AD,PAK);
          WRITE (F6,LAML,AD,W);      END;
        END.
```

APPENDIX 6-B

AIR TRAFFIC CONTROL COST MODEL

6-B-1 Cost Model Flow Diagram

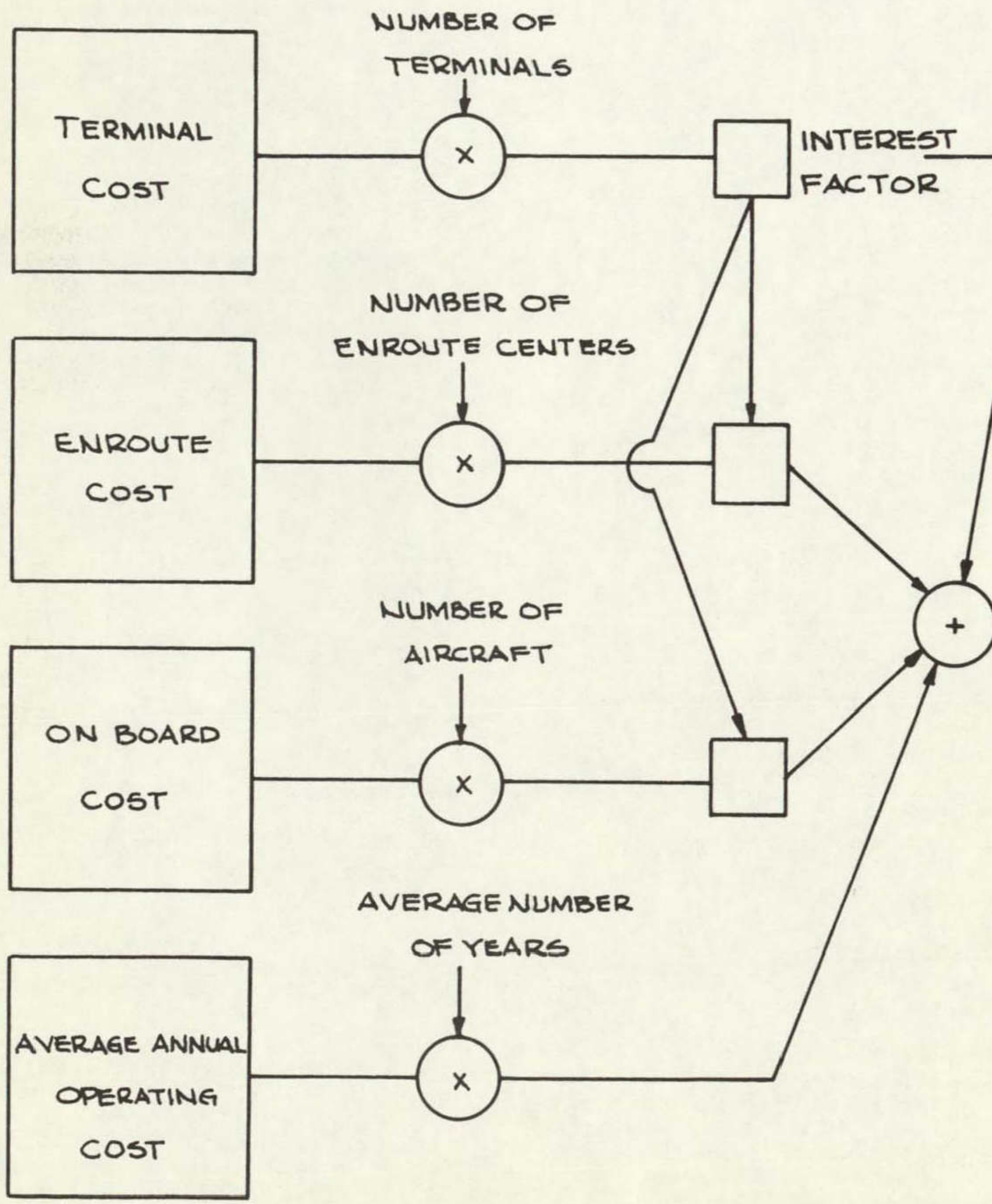

Figure 6-B-1

6-B-2 Computer Printout

The following is the actual computer printout of the Cost Model written in the UNIVAC 1108 Algol computer language (for unidentified nomenclature see Appendix 6-A).

```
INTEGER E;
FOR E=1 STEP 1 UNTIL 36 DO
        BEGIN
          INTEGER I,L,J,SEP,EXT,CLR,ID,N,M,LCTOL,U,V,W,X,Y,Z,UU,VV,
         WW,XX,K,P,Q,NOTH;
INTEGER DOL;
          INTEGER ARRAY MIX[0:25],CID[0:11,0:5],TAP[0:11],TMAX[0:11],
             LAMS[0:11],CTL[0:11],LSTOL[0:11],ACT[0:11,0:5],
             ACCL[0:11,0:5],A[0:11],B[0:11],
             RWSTOL[0:11],RWCTOL[0:11],NOAC[0:5];
INTEGER ARRAY CTOLAP[0:11],STOLAP[0:11],STCTAP[0:11];
          REAL AA,BB,CAREA1,SAREA1,SEXAREA1,CEXAREA1,CTAXI1,STAXI1,
                CAREA2,SAREA2,SEXAREA2,CEXAREA2,CTAXI2,STAXI2,ACRES;
          REAL ARRAY WCMAX[0:11],    PCTOL[0:11,0:5],PSTOL[0:11,0:5],
        TPCT[0:11,0:5],PS[0:11],CTOTAREA[0:11],STOTAREA[0:11],
         CTOTEX[0:11],STOTEX[0:11],CAVETAXI[0:11],SAVETAXI[0:11],
        TOTOPS[0:5],TOT[0:5],AVEGRDELAY[0:5],SUM[0:5],
        AVEAIRDELAY[0:5],GSDELAY[0:11],GCDELAY[0:11],ASDELAY[0:11],
        ACDELAY[0:11],TOTLINFTRUN[0:11],PCT[0:11,0:5],WSMAX[0:11];
FORMAT  TR1('PS=',D10.5,A1);
FORMAT TR2('A=',D10.5,'B=',D10.5,A1);
FORMAT TR4('CX=',D10.5,A1);
          FORMAT       AC('25,',I2,',',D4.2,',',D4.2,',',A1);
          FORMAT       TM2('27',I3,I10,I10,I10,I10,I10,I3,A1);
          FORMAT       TM1('23',I3,I10,I10,I10,I10,I10,I3,A1);
          FORMAT       EF('24',I4,I5,I5,I5,I5,I5,I5,A1);
FORMAT DR1(A,I2,I1,I2,I5,I5,I5,I5,I5,I5,I5,I5,I5);
               FORMAT   DR2(A,I2,I3,I5,I5,I5,I5,I5);
               FORMAT   DR3(A,I2,I3,I5,D8.3,I5,D8.3,D7.3);
FORMAT DR3OUT(I2,I5,I5,D8.3,I5,D8.3,D7.3,A1);
FORMAT DR2OUT(I2,I5,I5,I5,I5,I5,I5,A1);
FORMAT DR1OUT(  I2,I1,I2,I5,I5,I5,I5,I5,I5,I5,I5,I5,A1);
FORMAT FMT(A,I10);
      FORMAT FMT1('ERROR IN CALCULATING A/C CLASS PCT',A1);
               FORMAT FMT2('NUMBER OF RUNWAYS TOO LARGE',A1);
               FORMAT FMT3('WRONG SET OF INPUT DATA',A1);
    FORMAT FMT4('SELECTION OF AIRPORT CONFIGURATION INCORRECT',A1);
               FORMAT FMT7('AIRPORT TYPE IS IN ERROR',A1);
FORMAT EFFHEADA(X18,'CONTROL OUTPUT FOR EFFECTIVENESS (DATA NO. 24)',
A1);
FORMAT EFFHEADB('CITY',X7,'AIR HOLD TIME[MIN]:',X6,'GROUND HOLD TIME',
            '[MIN]:',X4,'AVE TAXI TIME[MIN]:',A1);
FORMAT EFFHEADC(X1,'NO.',X8,'STOL',X5,'CTOL',X15,'STOL',X5,'CTOL',X11,
             'STOL',X6,'CTOL',A1);
FORMAT EFFDATA(I3,X9,I4,X5,I4,X15,I4,X5,I4,X11,I4,X6,I4,A1);
FORMAT TERMHEADA(X18,'CONTROL OUTPUT FOR TERMINALS (DATA NO. 23)',A1);
FORMAT TERMHEADB(X2,'CITY',X3,'TOTAL RUNWAY ACREA:',X2,'EXCESS RUNWAY',
             ' ACRES:',X2,'LINEAR FEET OF',A1);
FORMAT TERMHEADC(X3,'NO.',X5,'STOL',X5,'CTOL',X8,'STOL',X5,'CTOL',X8,
             'CTOL RUNWAY',X5,'STOL RUNWAYS',A1);
FORMAT TERMDATA(X3,I2,X5,I6,X3,I6,X6,I6,X3,I7,X6,I7,X14,I2,A1);
FORMAT ACHEADA(X21,'CONTROL OUTPUT FOR AIRCRAFT (DATANO. 25)',A1);
```

```
FORMAT ACHEADB(X7,'A/C IDENT. NO.',X12,'AVE. GROUND HOLD TIME',X6,
               'AIR HOLD TIME',A1);
FORMAT ACDATA(X11,I2,X29,D5.2,X23,D5.2,A1);
FORMAT STAR(100('*'),A1);
FORMAT EJECT(E2);
FORMAT RM1('  NO.',I3,' RUN',I11,' MINUTES MAX. DELAY',X7,
          'NO.',I2,' CONTROL PACKAGE',I12,' DOLS CTR COST  *',A1);
FORMAT RM2('*',I2,'*',I3,' *',I3,' *',I5,'     *',I3,' *',I3,' *',
I4,'*',I4,'*',I4,'*'I4,'*',I5,'*',I3,' *',I3,' *',
          I3,' *',I3,' *',I3,' *',I3,' *',I5,' *',I2,'*',A1);
FORMAT RM3('*',I4,' *',I4,' *',D4.2,' *',D4.2,' *',A1);

          PROCEDURE AREA(CTOL,STOL,LCTOL,LSTO ,SEP,CLR,EXT,
                         CAREA,SAREA,CEXAREA,SEXAREA,CTAXI,STAXI);
          INTEGER CTOL,STOL,LCTOL,LSTO ,SEP,CLR,EXT;
            REAL CAREA,SAREA,SEXAREA,CEXAREA,STAXI,CTAXI;
            BEGIN
              REAL CX;
              INTEGER K;
;COMMENT CHECK FOR CTOL EQUAL ZERO;
          IF CTOL LEQ 0 THEN BEGIN CAREA=0.0;CEXAREA=0.0;GO TO L1 END;
              CAREA=(LCTOL+2.0*EXT)*(CTOL*SEP-SEP+2.0*CLR+150.0);
              CEXAREA=CAREA-(150.0+2.0*CLR)*(LCTOL+2.0*EXT);
;COMMENT CHECK FOR CTOL EQL ZERO;
      L1:  IF STOL LEQ 0 THEN BEGIN SAREA=0.0; SEXAREA=0.0; GO TO L2
                END;
              SAREA=(LSTO +2.0*EXT)*(STOL*SEP-SEP+2.0*CLR+150.0);
              SEXAREA=SAREA-(150.0+2.0*CLR)*(LSTO +2.0*EXT);
        L2:   K=0;CX=0.0;
        L3:   K=K+1;
              IF K GTR STOL THEN GO TO L4;
;COMMENT     CX IS HERE LENGTH OF RWAY TIMES DIST FROM LEFT FOR STOL;
              CX=CX+(LSTO *SEP*(K-1));
              GO TO L3;
        L4:   K=0;
        L5:   K=K+1;
              IF K GTR CTOL THEN GO TO L6;
;COMMENT CX HERE IS DIST TIMES RWAY LENGTH FOR STOL AND CTOL;
              CX=CX+(LCTOL*(STOL+K-1)*SEP);
              GO TO L5;
;COMMENT  CX HERE IS RWAY LENGTH TIMES DIST DIVIDED BY TOTAL LENGTH;
        L6:   CX=CX/(STOL*LSTO +CTOL*LCTOL);
;COMMENT CX IS DISTANCE TO CENTROID, STATT CALCULATING TAXI TIME;
K=0; STAXI=0.0;
        L7:   K=K+1;
              IF K GTR STOL THEN GO TO L8;
              STAXI=STAXI+SQRT(((K-1)*SEP-CX)**2.0+(LSTO /2.0)**2.0);
              GO TO L7;
;COMMENT CALCULATE CTOL TAXI TIME;
         L8:  K=0 ; CTAXI=0.0;
        L9: K=K+1;
        IF K GTR CTOL THEN GO TO L10;
    CTAXI=CTAXI+SQRT(((STOL+K-1)*SEP-CX)**2.0+(LCTOL/2.0)**2.0);
              GO TO L9;
       L10:   STAXI=STAXI/36.667;
              CTAXI=CTAXI/36.667;

            END AREA ;
```

```
PROCEDURE       CALRCF(RALT,RCF);
   REAL         RALT;
   REAL ARRAY RCF;
   BEGIN
          RCF[1]=.03*RALT/1000+.99;
          RCF[2]=.19*RALT/6000+.99;
         RCF[3]=.22*RALT/6000+.99;
          RCF[4]=.24*RALT/6000+.99;
          RCF[5]=.16*RALT/3500+.99;

   END CALRCF;

PROCEDURE       CALER(RCF,RLEN,CRLEN,P,ER,HSTURNO);
   VALUE        P;
   INTEGER      P;
   REAL         RLEN;
   REAL ARRAY CRLEN,ER,RCF,HSTURNO;
   BEGIN
         INTEGER I,N;
         REAL ARRAY  ERL,ERU,TURNOF[0:5];
          FOR I=1 STEP 1 UNTIL 5 DO CRLEN[I]=1.1*RCF[I]*RLEN;
          IF CRLEN[1] LEQ  5399 THEN GO TO ERR ELSE
     IF CRLEN[1] LEQ  6199  THEN BEGIN ERL[1]=2700;ERU[1]=4500;END  ELSE
     IF CRLEN[1] LEQ  6999  THEN BEGIN ERL[1]=2900;ERU[1]=5000;END  ELSE
     IF CRLEN[1] LEQ  7999  THEN BEGIN ERL[1]=3050;ERU[1]=5500;END  ELSE
     IF CRLEN[1] LEQ  8999  THEN BEGIN ERL[1]=3200;ERU[1]=5900;END  ELSE
     IF CRLEN[1] LEQ  9999  THEN BEGIN ERL[1]=3350;ERU[1]=6100;END  ELSE
     IF CRLEN[1] LEQ  10999 THEN BEGIN ERL[1]=3500;ERU[1]=6400;END  ELSE
     IF CRLEN[1] LEQ  11999 THEN BEGIN ERL[1]=3650;ERU[1]=6600;END  ELSE
          BEGIN ERL[1]=3800;ERU[1]=6800;END;
     IF CRLEN[2] LEQ  5399  THEN BEGIN ERL[2]=1700;ERU[2]=3850;END  ELSE
     IF CRLEN[2] LEQ  6199  THEN BEGIN ERL[2]=1800;ERU[2]=3900;END  ELSE
     IF CRLEN[2] LEQ  6999  THEN BEGIN ERL[2]=1900;ERU[2]=4100;END  ELSE
     IF CRLEN[2] LEQ  7999  THEN BEGIN ERL[2]=2000;ERU[2]=4300;END  ELSE
     IF CRLEN[2] LEQ  8999  THEN BEGIN ERL[2]=2100;ERU[2]=4500 END  ELSE
     IF CRLEN[2] LEQ  9999  THEN BEGIN ERL[2]=2200;ERU[2]=4650 END  ELSE
     IF CRLEN[2] LEQ  10999 THEN BEGIN ERL[2]=2300;ERU[2]=4800 END  ELSE
     IF CRLEN[2] LEQ  11999 THEN BEGIN ERL[2]=2400;ERU[2]=4950 END  ELSE
          BEGIN ERL[2]=2500;ERU[2]=5100;END;
     IF CRLEN[3] LEQ  5399  THEN BEGIN ERL[3]=1100;ERU[3]=2700 END  ELSE
     IF CRLEN[3] LEQ  6199  THEN BEGIN ERL[3]=1300;ERU[3]=2900 END  ELSE
     IF CRLEN[3] LEQ  6999  THEN BEGIN ERL[3]=1450;ERU[3]=3100 END  ELSE
     IF CRLEN[3] LEQ  7999  THEN BEGIN ERL[3]=1600;ERU[3]=3300 END  ELSE
     IF CRLEN[3] LEQ  8999  THEN BEGIN ERL[3]=1700;ERU[3]=3500 END  ELSE
     IF CRLEN[3] LEQ  9999  THEN BEGIN ERL[3]=1750;ERU[3]=3600 END  ELSE
     IF CRLEN[3] LEQ  10999 THEN BEGIN ERL[3]=1750;ERU[3]=3650 END  ELSE
     IF CRLEN[3] LEQ  11999 THEN BEGIN ERL[3]=1800;ERU[3]=3700 END  ELSE
          BEGIN ERL[3]=1800;ERU[3]=3700;END;
     IF CRLEN[3] LEQ  5399  THEN BEGIN ERL[4]=850 ;ERU[4]=2400 END  ELSE
     IF CRLEN[4] LEQ  6199  THEN BEGIN ERL[4]=950 ;ERU[4]=2500 END  ELSE
     IF CRLEN[4] LEQ  6999  THEN BEGIN ERL[4]=1000;ERU[4]=2600 END  ELSE
     IF CRLEN[4] LEQ  7999  THEN BEGIN ERL[4]=1050;ERU[4]=2900 END  ELSE
     IF CRLEN[4] LEQ  8999  THEN BEGIN ERL[4]=1050;ERU[4]=3200 END  ELSE
     IF CRLEN[4] LEQ  9999  THEN BEGIN ERL[4]=1100;ERU[4]=3300 END  ELSE
     IF CRLEN[4] LEQ  10999 THEN BEGIN ERL[4]=1150;ERU[4]=3350 END  ELSE
     IF CRLEN[4] LEQ  11999 THEN BEGIN ERL[4]=1200;ERU[4]=3400 END  ELSE
          BEGIN ERL[4]=1250;ERU[4]=3400;END;
```

```
    IF CRLEN[5] LEQ  5399  THEN BEGIN ERL[5]=700 ;ERU[5]=1700 END  ELSE
    IF CRLEN[5] LEQ  6199  THEN BEGIN ERL[5]=700 ;ERU[5]=1850 END  ELSE
    IF CRLEN[5] LEQ  6999  THEN BEGIN ERL[5]=700 ;ERU[5]=2000 END  ELSE
    IF CRLEN[5] LEQ  7999  THEN BEGIN ERL[5]=750 ;ERU[5]=2150 END  ELSE
    IF CRLEN[5] LEQ  8999  THEN BEGIN ERL[5]=800 ;ERU[5]=2300 END  ELSE
    IF CRLEN[5] LEQ  9999  THEN BEGIN ERL[5]=900 ;ERU[5]=2400 END  ELSE
    IF CRLEN[5] LEQ  10999 THEN BEGIN ERL[5]=950 ;ERU[5]=2500 END  ELSE
     IF CRLEN[5] LEQ 11999 THEN BEGIN ERL[5]=1000;ERU[5]=2600 END ELSE
         BEGIN ERL[5]=1000;ERU[5]=2700;END;
         FOR I=1 STEP 1 UNTIL 5 DO TURNOF[I]=0;
         FOR I=1 STEP 1 UNTIL 5 DO     FOR N=1 STEP 1 UNTIL P DO
         IF HSTURNO[N] LEQ ERU[I] AND HSTURNO[N] GEQ ERL[I] THEN
         TURNOF[I]=TURNOF[I]+1;
     FOR I=1 STEP 1 UNTIL 5 DO IF TURNOF[I] EQL 0 THEN ER[I]=4 ELSE
    IF TURNOF[I] EQL 1 THEN ER[I]=2 ELSE IF TURNOF[I] EQL 2 THEN ER[I]=2
         ELSE ER[I]=1;           GO TO L1;
ERR:  WRITE('UNACEPT RUNWAY LENGTH');

L1:  END CALER;

PROCEDURE       CALRRATING(CRLEN,ER,PCT,RRATING);
   REAL ARRAY CRLEN,ER,PCT;       REAL RRATING;
   BEGIN
        INTEGER I,N;
        REAL ARRAY RR,IRR[0:5];
         IF CRLEN[1] LEQ 5399 THEN GO TO ERR ELSE
         IF CRLEN[1] LEQ 6199  THEN BEGIN
                       IF ER[1] EQL  1 THEN RR[1]=42 ELSE
                       IF ER[1] EQL  2 THEN RR[1]=46 ELSE
                       IF ER[1] EQL 3 THEN  RR[1]=50 ELSE RR[1]=59 END
    ELSE IF CRLEN[1] LEQ  6999 THEN BEGIN
                       IF ER[1] EQL  1 THEN RR[1]=43 ELSE
                       IF ER[1] EQL  2 THEN RR[1]=47 ELSE
                       IF ER[1] EQL 3 THEN  RR[1]=51 ELSE RR[1]=59 END
    ELSE IF CRLEN[1] LEQ  7999 THEN BEGIN
                       IF ER[1] EQL  1 THEN RR[1]=44 ELSE
                       IF ER[1] EQL  2 THEN RR[1]=47 ELSE
                       IF ER[1] EQL 3 THEN  RR[1]=52 ELSE RR[1]=60 END
    ELSE IF CRLEN[1] LEQ  8999 THEN BEGIN
                       IF ER[1] EQL  1 THEN RR[1]=45 ELSE
                       IF ER[1] EQL  2 THEN RR[1]=48 ELSE
                       IF ER[1] EQL 3 THEN  RR[1]=53 ELSE RR[1]=61 END
    ELSE IF CRLEN[1] LEQ  9999 THEN BEGIN
                       IF ER[1] EQL  1 THEN RR[1]=45 ELSE
                       IF ER[1] EQL  2 THEN RR[1]=49 ELSE
                       IF ER[1] EQL 3 THEN  RR[1]=54 ELSE RR[1]=64 END
    ELSE IF CRLEN[1] LEQ  10999THEN BEGIN
                       IF ER[1] EQL  1 THEN RR[1]=45 ELSE
                       IF ER[1] EQL  2 THEN RR[1]=50 ELSE
                       IF ER[1] EQL 3 THEN  RR[1]=55 ELSE RR[1]=66 END
    ELSE IF CRLEN[1] LEQ  11999THEN BEGIN
                       IF ER[1] EQL  1 THEN RR[1]=46 ELSE
                       IF ER[1] EQL  2 THEN RR[1]=52 ELSE
                       IF ER[1] EQL 3 THEN  RR[1]=58 ELSE RR[1]=68 END
         ELSE BEGIN
                       IF ER[1] EQL  1 THEN RR[1]=46 ELSE
                       IF ER[1] EQL  1 THEN RR[1]=53 ELSE
                       IF ER[1] EQL 3 THEN  RR[1]=60 ELSE RR[1]=70 END;
```

```
      IF CRLEN[2] LEQ 4299 THEN GO TO ERR ELSE
      IF CRLEN[2] LEQ 5399  THEN BEGIN
                           IF ER[2] EQL  1 THEN RR[2]=36 ELSE
                           IF ER[2] EQL  2 THEN RR[2]=38 ELSE
                           IF ER[2] EQL 3 THEN  RR[2]=40 ELSE RR[2]=48 END
ELSE IF CRLEN[2] LEQ  6199 THEN BEGIN
                           IF ER[2] EQL  1 THEN RR[2]=37 ELSE
                           IF ER[2] EQL  2 THEN RR[2]=39 ELSE
                           IF ER[2] EQL 3 THEN  RR[2]=41 ELSE RR[2]=51 END
ELSE IF CRLEN[2] LEQ  6999 THEN BEGIN
                           IF ER[2] EQL  1 THEN RR[2]=38 ELSE
                           IF ER[2] EQL  2 THEN RR[2]=40 ELSE
                           IF ER[2] EQL 3 THEN  RR[2]=42 ELSE RR[2]=53 END
ELSE IF CRLEN[2] LEQ  7999 THEN BEGIN
                           IF ER[2] EQL  1 THEN RR[2]=39 ELSE
                           IF ER[2] EQL  2 THEN RR[2]=41 ELSE
                           IF ER[2] EQL 3 THEN  RR[2]=43 ELSE RR[2]=55 END
ELSE IF CRLEN[2] LEQ  8999 THEN BEGIN
                           IF ER[2] EQL  1 THEN RR[2]=39 ELSE
                           IF ER[2] EQL  2 THEN RR[2]=42 ELSE
                           IF ER[2] EQL 3 THEN  RR[2]=45 ELSE RR[2]=57 END
ELSE IF CRLEN[2] LEQ  9999 THEN BEGIN
                           IF ER[2] EQL  1 THEN RR[2]=40 ELSE
                           IF ER[2] EQL  2 THEN RR[2]=44 ELSE
                           IF ER[2] EQL 3 THEN  RR[2]=49 ELSE RR[2]=59 END
ELSE IF CRLEN[2] LEQ  10999THEN BEGIN
                           IF ER[2] EQL  1 THEN RR[2]=40 ELSE
                           IF ER[2] EQL  2 THEN RR[2]=46 ELSE
                           IF ER[2] EQL 3 THEN  RR[2]=50 ELSE RR[2]=60 END
ELSE IF CRLEN[2] LEQ  11999THEN BEGIN
                           IF ER[2] EQL  1 THEN RR[2]=41 ELSE
                           IF ER[2] EQL  2 THEN RR[2]=47 ELSE
                           IF ER[2] EQL 3 THEN  RR[2]=51 ELSE RR[2]=62 END
      ELSE BEGIN
                           IF ER[2] EQL  1 THEN RR[2]=41 ELSE
                           IF ER[2] EQL  2 THEN RR[2]=48 ELSE
                           IF ER[2] EQL 3 THEN  RR[2]=52 ELSE RR[2]=63 END;
      IF CRLEN[3] LEQ 2999 THEN GO TO ERR ELSE
      IF CRLEN[3] LEQ 4299  THEN BEGIN
                           IF ER[3] EQL  1 THEN RR[3]=30 ELSE
                           IF ER[3] EQL  2 THEN RR[3]=35 ELSE
                           IF ER[3] EQL 3 THEN  RR[3]=38 ELSE RR[3]=41 END
ELSE IF CRLEN[3] LEQ  5399 THEN BEGIN
                           IF ER[3] EQL  1 THEN RR[3]=32 ELSE
                           IF ER[3] EQL  2 THEN RR[3]=36 ELSE
                           IF ER[3] EQL 3 THEN  RR[3]=39 ELSE RR[3]=44 END
ELSE IF CRLEN[3] LEQ  6199 THEN BEGIN
                           IF ER[3] EQL  1 THEN RR[3]=33 ELSE
                           IF ER[3] EQL  2 THEN RR[3]=38 ELSE
                           IF ER[3] EQL 3 THEN  RR[3]=41 ELSE RR[3]=49 END
ELSE IF CRLEN[3] LEQ  6999 THEN BEGIN
                           IF ER[3] EQL  1 THEN RR[3]=34 ELSE
                           IF ER[3] EQL  2 THEN RR[3]=39 ELSE
                           IF ER[3] EQL 3 THEN  RR[3]=43 ELSE RR[3]=52 END
ELSE IF CRLEN[3] LEQ  7999 THEN BEGIN
                           IF ER[3] EQL  1 THEN RR[3]=35 ELSE
                           IF ER[3] EQL  2 THEN RR[3]=41 ELSE
                           IF ER[3] EQL 3 THEN  RR[3]=45 ELSE RR[3]=54 END
```

```
ELSE IF CRLEN[3] LEQ  8999 THEN BEGIN
                   IF ER[3] EQL  1 THEN RR[3]=36 ELSE
                   IF ER[3] EQL  2 THEN RR[3]=42 ELSE
                   IF ER[3] EQL 3 THEN  RR[3]=47 ELSE RR[3]=55 END
ELSE IF CRLEN[3] LEQ  9999 THEN BEGIN
                   IF ER[3] EQL  1 THEN RR[3]=37 ELSE
                   IF ER[3] EQL  2 THEN RR[3]=43 ELSE
                   IF ER[3] EQL 3 THEN  RR[3]=48 ELSE RR[3]=56 END
ELSE IF CRLEN[3] LEQ  10999THEN BEGIN
                   IF ER[3] EQL  1 THEN RR[3]=38 ELSE
                   IF ER[3] EQL  2 THEN RR[3]=44 ELSE
                   IF ER[3] EQL 3 THEN  RR[3]=48 ELSE RR[3]=57 END
ELSE IF CRLEN[3] LEQ  11999THEN BEGIN
                   IF ER[3] EQL  1 THEN RR[3]=39 ELSE
                   IF ER[3] EQL  2 THEN RR[3]=45 ELSE
                   IF ER[4] EQL 3 THEN  RR[3]=49 ELSE RR[3]=58 END
     ELSE BEGIN
                   IF ER[3] EQL  1 THEN RR[3]=40 ELSE
                   IF ER[3] EQL  2 THEN RR[3]=46 ELSE
                   IF ER[3] EQL 3 THEN  RR[3]=49 ELSE RR[3]=59 END;
     IF CRLEN [4] LEQ 2999  THEN BEGIN
                   IF ER[4] EQL  1 THEN RR[4]=20 ELSE
                   IF ER[4] EQL  2 THEN RR[4]=27 ELSE
                   IF ER[4] EQL 3 THEN  RR[4]=33 ELSE RR[4]=39 END
ELSE IF CRLEN[4] LEQ  4299 THEN BEGIN
                   IF ER[4] EQL  1 THEN RR[4]=22 ELSE
                   IF ER[4] EQL  2 THEN RR[4]=30 ELSE
                   IF ER[4] EQL 3 THEN  RR[4]=35 ELSE RR[4]=40 END
ELSE IF CRLEN[4] LEQ  5399 THEN BEGIN
                   IF ER[4] EQL  1 THEN RR[4]=24 ELSE
                   IF ER[4] EQL  2 THEN RR[4]=31 ELSE
                   IF ER[4] EQL 3 THEN  RR[4]=37 ELSE RR[4]=41 END
ELSE IF CRLEN[4] LEQ  6199 THEN BEGIN
                   IF ER[4] EQL  1 THEN RR[4]=25 ELSE
                   IF ER[4] EQL  2 THEN RR[4]=32 ELSE
                   IF ER[4] EQL 3 THEN  RR[4]=38 ELSE RR[4]=42 END
ELSE IF CRLEN[4] LEQ  6999 THEN BEGIN
                   IF ER[4] EQL  1 THEN RR[4]=26 ELSE
                   IF ER[4] EQL  2 THEN RR[4]=33 ELSE
                   IF ER[4] EQL 3 THEN  RR[4]=38 ELSE RR[4]=43 END
ELSE IF CRLEN[4] LEQ  7999 THEN BEGIN
                   IF ER[4] EQL  1 THEN RR[4]=27 ELSE
                   IF ER[4] EQL  2 THEN RR[4]=24 ELSE
                   IF ER[4] EQL 3 THEN  RR[4]=39 ELSE RR[4]=45 END
ELSE IF CRLEN[4] LEQ  8999 THEN BEGIN
                   IF ER[4] EQL  1 THEN RR[4]=28 ELSE
                   IF ER[4] EQL  2 THEN RR[4]=35 ELSE
                   IF ER[4] EQL 3 THEN  RR[4]=41 ELSE RR[4]=47 END
ELSE IF CRLEN[4] LEQ  9999 THEN BEGIN
                   IF ER[4] EQL  1 THEN RR[4]=30 ELSE
                   IF ER[4] EQL  2 THEN RR[4]=36 ELSE
                   IF ER[4] EQL 3 THEN  RR[4]=42 ELSE RR[4]=48 END
ELSE IF CRLEN[4] LEQ  10999THEN BEGIN
                   IF ER[4] EQL  1 THEN RR[4]=32 ELSE
                   IF ER[4] EQL  2 THEN RR[4]=37 ELSE
                   IF ER[4] EQL 3 THEN  RR[4]=44 ELSE RR[4]=49 END
ELSE IF CRLEN[4] LEQ  11999THEN BEGIN
                   IF ER[4] EQL  1 THEN RR[4]=34 ELSE
```

```
                    IF ER[4] EQL  2 THEN RR[4]=39 ELSE
                    IF ER[4] EQL 3 THEN  RR[4]=45 ELSE RR[4]=51 END
       ELSE BEGIN
                    IF ER[4] EQL  1 THEN RR[4]=35 ELSE
                    IF ER[4] EQL  2 THEN RR[4]=41 ELSE
                    IF ER[4] EQL 3 THEN  RR[4]=46 ELSE RR[4]=53 END;
       IF CRLEN [5] LEQ 2999  THEN BEGIN
                    IF ER[5] EQL  1 THEN RR[5]=21 ELSE
                    IF ER[5] EQL  2 THEN RR[5]=28 ELSE
                    IF ER[5] EQL 3 THEN  RR[5]=33 ELSE RR[5]=39 END
   ELSE IF CRLEN[5] LEQ  4299 THEN BEGIN
                    IF ER[5] EQL  1 THEN RR[5]=25 ELSE
                    IF ER[5] EQL  2 THEN RR[5]=29 ELSE
                    IF ER[5] EQL 3 THEN  RR[5]=34 ELSE RR[5]=40 END
   ELSE IF CRLEN[5] LEQ  5399 THEN BEGIN
                    IF ER[5] EQL  1 THEN RR[5]=27 ELSE
                    IF ER[5] EQL  2 THEN RR[5]=30 ELSE
                    IF ER[5] EQL 3 THEN  RR[5]=35 ELSE RR[5]=42 END
   ELSE IF CRLEN[5] LEQ  6199 THEN BEGIN
                    IF ER[5] EQL  1 THEN RR[5]=28 ELSE
                    IF ER[5] EQL  2 THEN RR[5]=31 ELSE
                    IF ER[5] EQL 3 THEN  RR[5]=36 ELSE RR[5]=44 END
   ELSE IF CRLEN[5] LEQ  6999 THEN BEGIN
                    IF ER[5] EQL  1 THEN RR[5]=29 ELSE
                    IF ER[5] EQL  2 THEN RR[5]=32 ELSE
                    IF ER[5] EQL 3 THEN  RR[5]=37 ELSE RR[5]=46 END
   ELSE IF CRLEN[5] LEQ  7999 THEN BEGIN
                    IF ER[5] EQL  1 THEN RR[5]=30 ELSE
                    IF ER[5] EQL  2 THEN RR[5]=33 ELSE
                    IF ER[5] EQL 3 THEN  RR[5]=38 ELSE RR[5]=48 END
   ELSE IF CRLEN[5] LEQ  8999 THEN BEGIN
                    IF ER[5] EQL  1 THEN RR[5]=31 ELSE
                    IF ER[5] EQL  2 THEN RR[5]=34 ELSE
                    IF ER[5] EQL 3 THEN  RR[5]=39 ELSE RR[5]=50 END
   ELSE IF CRLEN[5] LEQ  9999 THEN BEGIN
                    IF ER[5] EQL  1 THEN RR[5]=32 ELSE
                    IF ER[5] EQL  2 THEN RR[5]=36 ELSE
                    IF ER[5] EQL 3 THEN  RR[5]=40 ELSE RR[5]=52 END
   ELSE IF CRLEN[5] LEQ  10999THEN BEGIN
                    IF ER[5] EQL  1 THEN RR[5]=33 ELSE
                    IF ER[5] EQL  2 THEN RR[5]=37 ELSE
                    IF ER[5] EQL 3 THEN  RR[5]=41 ELSE RR[5]=53 END
   ELSE IF CRLEN[5] LEQ  11999THEN BEGIN
                    IF ER[5] EQL  1 THEN RR[5]=34 ELSE
                    IF ER[5] EQL  2 THEN RR[5]=39 ELSE
                    IF ER[5] EQL 3 THEN  RR[5]=43 ELSE RR[5]=54 END
       ELSE BEGIN
                    IF ER[5] EQL  1 THEN RR[5]=35 ELSE
                    IF ER[5] EQL  2 THEN RR[5]=40 ELSE
                    IF ER[5] EQL 3 THEN  RR[5]=45 ELSE RR[5]=55 END;
       FOR I=1 STEP 1 UNTIL 5 DO IRR[I]=RR[I]*PCT[I];
       RRATING=IRR[1]+IRR[2]+IRR[3]+IRR[4]+IRR[5];      GO TO L2;
ERR:  WRITE ('UNACCEPT RUNWAY LENGTH');

L2:  END CALRRATING;

PROCEDURE      CALR(LAML,RRATING,R,PAK);   INTEGER      PAK;
   REAL        LAML,RRATING,R;
```

```
   BEGIN
         IF LAML LEQ 20 THEN R=RRATING*(1.216-.0108*LAML) ELSE
         IF LAML LEQ 30 THEN R=RRATING*(1.1-.005*LAML) ELSE
         IF LAML LEQ 40 THEN R=RRATING*(1.0325-.00275*LAML) ELSE
     BEGIN IF RRATING GEQ 65 THEN R=RRATING*.925 ELSE R=RRATING*.927 END;
IF PAK EQL 2 THEN R=R*.9 ELSE IF PAK EQL 3 THEN R=R*.9;
WRITE('RUNWAY RATING=',R);

   END;

PROCEDURE       CALC1(PCT,C1,PAK);
        INTEGER PAK;
   REAL         C1;
   REAL ARRAY  PCT;
   BEGIN
        REAL ARRAY C[0:5];
        C[1]=28;C[2]=19;C[3]=16;C[4]=14;C[5]=10;
       C1=C[1]*PCT[1]+C[2]*PCT[2]+C[3]*PCT[3]+C[4]*PCT[4]+C[5]*PCT[5];
IF PAK EQL 2 THEN C1=C1*.88 ELSE IF PAK EQL 3 THEN C1=C1*.88;

   END;

PROCEDURE       CALF1(PCT,F1,PAK);        INTEGER   PAK;
   REAL         F1;
   REAL ARRAY  PCT;
   BEGIN
        INTEGER I,N;
        REAL ARRAY F,FF[0:5,0:5];
        F[1,1]=56;F[1,2]=74;F[1,3]=83;F[1,4]=66;F[1,5]=86;
        F[2,1]=56;F[2,2]=43;F[2,3]=50;F[2,4]=66;F[2,5]=86;
        F[3,1]=56;F[3,2]=43;F[3,3]=50;F[3,4]=66;F[3,5]=86;
        F[4,1]=56;F[4,2]=43;F[4,3]=50;F[4,4]=66;F[4,5]=86;
        F[5,1]=56;F[5,2]=43;F[5,3]=50;F[5,4]=66;F[5,5]=86;
        FF[0,0]=0;FF[0,1]=0;FF[0,2]=0;FF[0,3]=0;FF[0,4]=0;
        FOR I=1 STEP 1 UNTIL 5 DO FOR N=1 STEP 1 UNTIL 5 DO
     FF[I,N]=PCT[I]*PCT[N]*F[I,N];
      F1=FF[1,1]+FF[1,2]+FF[1,3]+FF[1,4]+FF[1,5]+
         FF[2,1]+FF[2,2]+FF[2,3]+FF[2,4]+FF[2,5]+
         FF[3,1]+FF[3,2]+FF[3,3]+FF[3,4]+FF[3,5]+
         FF[4,1]+FF[4,2]+FF[4,3]+FF[4,4]+FF[4,5]+
       FF[5,1]+FF[5,2]+FF[5,3]+FF[5,4]+FF[5,5];
        IF PAK EQL 2 THEN F1=F1*.82 ELSE IF PAK EQL 3 THEN F1=F1*.66;

   END;

PROCEDURE       CALT(LAMS,PCT,T,PAK);        INTEGER   PAK;
   REAL         LAMS,T;
   REAL ARRAY  PCT;
   BEGIN
        REAL ARRAY TT,TAM[0:5,0:5];
        INTEGER  I,N;
    IF LAMS LEQ  10 THEN TAM[1,1]=94.2  ELSE
    IF LAMS LEQ  20 THEN TAM[1,1]=90.0  ELSE
    IF LAMS LEQ  30 THEN TAM[1,1]=87.5  ELSE
    IF LAMS LEQ  40 THEN TAM[1,1]=86.0  ELSE
    IF LAMS LEQ  50 THEN TAM[1,1]=86.0  ELSE
        TAM[1,1]=86.0;
    IF LAMS LEQ  10 THEN TAM[1,2]=85.2  ELSE
```

```
IF LAMS LEQ  20 THEN TAM[1,2]=81.2   ELSE
IF LAMS LEQ  30 THEN TAM[1,2]=79     ELSE
IF LAMS LEQ  40 THEN TAM[1,2]=77     ELSE
IF LAMS LEQ  50 THEN TAM[1,2]=77     ELSE
     TAM[1,2]=77.0;
     IF LAMS LEQ 10 THEN TAM[1,3]=100.8 ELSE
IF LAMS LEQ  20 THEN TAM[1,3]=83.2   ELSE
IF LAMS LEQ  30 THEN TAM[1,3]=74.8   ELSE
IF LAMS LEQ  40 THEN TAM[1,3]=69.4   ELSE
IF LAMS LEQ  50 THEN TAM[1,3]=67     ELSE
     TAM[1,3]=67.0;
IF LAMS LEQ  10 THEN TAM[1,4]=96.8   ELSE
IF LAMS LEQ  20 THEN TAM[1,4]=85.5   ELSE
IF LAMS LEQ  30 THEN TAM[1,4]=78.5   ELSE
IF LAMS LEQ  40 THEN TAM[1,4]=73.5   ELSE
IF LAMS LEQ  50 THEN TAM[1,4]=70.4   ELSE
     TAM[1,4]=67.5;
IF LAMS LEQ  10 THEN TAM[1,5]=96.8   ELSE
IF LAMS LEQ  20 THEN TAM[1,5]=85.5   ELSE
IF LAMS LEQ  30 THEN TAM[1,5]=78.5   ELSE
IF LAMS LEQ  40 THEN TAM[1,5]=73.5   ELSE
IF LAMS LEQ  50 THEN TAM[1,5]=70.4   ELSE
     TAM[1,5]=67.5;
IF LAMS LEQ  10 THEN TAM[2,1]=114.5  ELSE
IF LAMS LEQ  20 THEN TAM[2,1]=107    ELSE
IF LAMS LEQ  30 THEN TAM[2,1]=102.5  ELSE
     TAM[2,1]=100.0;
IF LAMS LEQ  10 THEN TAM[2,2]=110    ELSE
IF LAMS LEQ  20 THEN TAM[2,2]=89     ELSE
IF LAMS LEQ  30 THEN TAM[2,2]=78.5   ELSE
IF LAMS LEQ  40 THEN TAM[2,2]=72     ELSE
     TAM[2,2]=69.0;
IF LAMS LEQ  10 THEN TAM[2,3]=79     ELSE
IF LAMS LEQ  20 THEN TAM[2,3]=69.4   ELSE
IF LAMS LEQ  30 THEN TAM[2,3]=65.2   ELSE
IF LAMS LEQ  40 THEN TAM[2,3]=62     ELSE
IF LAMS LEQ  50 THEN TAM[2,3]=59.8   ELSE
     TAM[2,3]=59.0;
IF LAMS LEQ  10 THEN TAM[2,4]=108.3  ELSE
IF LAMS LEQ   20 THEN TAM[2,4]=77.5   ELSE
IF LAMS LEQ  30 THEN TAM[2,4]=63.8   ELSE
IF LAMS LEQ  40 THEN TAM[2,4]=55.8   ELSE
IF LAMS LEQ  50 THEN TAM[2,4]=49.5   ELSE
     TAM[2,4]=45.5;
     TAM[2,5]=TAM[2,4];
IF LAMS LEQ  10 THEN TAM[3,1]=145.5  ELSE
IF LAMS LEQ  20 THEN TAM[3,1]=126.4  ELSE
IF LAMS LEQ  30 THEN TAM[3,1]=117.3  ELSE
     TAM[3,1]=111.0;
IF LAMS LEQ  10 THEN TAM[3,2]=129    ELSE
IF LAMS LEQ  20 THEN TAM[3,2]=113.6  ELSE
IF LAMS LEQ  30 THEN TAM[3,2]=106    ELSE
     TAM[3,2]=101.0;
IF LAMS LEQ  10 THEN TAM[3,3]=97     ELSE
IF LAMS LEQ  20 THEN TAM[3,3]=84.5   ELSE
IF LAMS LEQ  30 THEN TAM[3,3]=78     ELSE
IF LAMS LEQ  40 THEN TAM[3,3]=74     ELSE
     TAM[3,3]=73.0;
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    IF LAMS LEQ  10 THEN TAM[3,4]=103.8 ELSE
    IF LAMS LEQ  20 THEN TAM[3,4]=84.2  ELSE
    IF LAMS LEQ  30 THEN TAM[3,4]=75.5  ELSE
    IF LAMS LEQ  40 THEN TAM[3,4]=69.5  ELSE
       TAM[3,4]=67.0;
       TAM[3,5]=TAM[3,4];
    IF LAMS LEQ  10 THEN TAM[4,1]=157   ELSE
    IF LAMS LEQ  20 THEN TAM[4,1]=150.2 ELSE
    IF LAMS LEQ  30 THEN TAM[4,1]=146   ELSE
       TAM[4,1]=143.0;
    IF LAMS LEQ  10 THEN TAM[4,2]=143   ELSE
    IF LAMS LEQ  20 THEN TAM[4,2]=136   ELSE
    IF LAMS LEQ  30 THEN TAM[4,2]=131.5 ELSE
       TAM[4,2]=143.0;
    IF LAMS LEQ  10 THEN TAM[4,3]=133.8 ELSE
       TAM[4,3]=100.0;
    IF LAMS LEQ  10 THEN TAM[4,4]=114.5 ELSE
    IF LAMS LEQ  20 THEN TAM[4,4]=91.2  ELSE
    IF LAMS LEQ  30 THEN TAM[4,4]=81.8  ELSE
    IF LAMS LEQ  40 THEN TAM[4,4]=76    ELSE
       TAM[4,4]=75.0;
       TAM[4,5]=TAM[4,4];
       TAM[5,1]=TAM[4,1];TAM[5,2]=TAM[4,2];TAM[5,3]=TAM[4,3];
       TAM[5,4]=TAM[4,4];TAM[5,5]=TAM[4,5];
       TT[0,1]=0;TT[0,2]=0;TT[0,3]=0;TT[0,4]=0;    TT[0,0]=0;
       FOR I=1 STEP 1 UNTIL 5 DO FOR N=1 STEP 1 UNTIL 5 DO
       TT[I,N]=PCT[I]*PCT[N]*TAM[I,N];
       T=TT[1,1]+TT[1,2]+TT[1,3]+TT[1,4]+TT[1,5]+
         TT[2,1]+TT[2,2]+TT[2,3]+TT[2,4]+TT[2,5]+
         TT[3,1]+TT[3,2]+TT[3,3]+TT[3,4]+TT[3,5]+
         TT[4,1]+TT[4,2]+TT[4,3]+TT[4,4]+TT[4,5]+
         TT[5,1]+TT[5,2]+TT[5,3]+TT[5,4]+TT[5,5];
IF PAK EQL 2 THEN T=T*.45 ELSE IF PAK EQL 3 THEN T=T*.45;

   END;

        PROCEDURE  CALA(LAML,PCT,A11,A22,PAK);
              INTEGER PAK;
              REAL LAML,A11,A22;
              REAL ARRAY PCT;
       BEGIN
   REAL ARRAY  AAM[0:5,0:5],TERM[0:25],A[0:5,0:5];
   INTEGER  I,J,K;
  IF LAML LEQ 10  THEN AAM[1,1]=179.0 ELSE
  IF LAML LEQ 20  THEN AAM[1,1]=172.0 ELSE
  IF LAML LEQ 30  THEN AAM[1,1]=168.0 ELSE
  IF LAML LEQ 40  THEN AAM[1,1]=165.0 ELSE
  IF LAML LEQ 50  THEN AAM[1,1]=164.0 ELSE
  AAM[1,1]=162.0;
  IF LAML LEQ 10  THEN AAM[1,2]=190.0 ELSE
  IF LAML LEQ 20  THEN AAM[1,2]=184.0 ELSE
  IF LAML LEQ 30  THEN AAM[1,2]=181.0 ELSE
  IF LAML LEQ 40  THEN AAM[1,2]=179.0 ELSE
  IF LAML LEQ 50  THEN AAM[1,2]=177.0 ELSE
  AAM[1,2]=176.0;
  IF LAML LEQ 10  THEN AAM[1,3]=220.0 ELSE
  IF LAML LEQ 20  THEN AAM[1,3]=200.0 ELSE
  IF LAML LEQ 30  THEN AAM[1,3]=189.0 ELSE
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IF LAML LEQ 40  THEN AAM[1,3]=182.0 ELSE
IF LAML LEQ 50  THEN AAM[1,3]=178.0 ELSE
AAM[1,3]=174.0;
IF LAML LEQ 10  THEN AAM[1,4]=226.0 ELSE
IF LAML LEQ 20  THEN AAM[1,4]=212.0 ELSE
IF LAML LEQ 30  THEN AAM[1,4]=204.0 ELSE
IF LAML LEQ 40  THEN AAM[1,4]=199.0 ELSE
IF LAML LEQ 50  THEN AAM[1,4]=196.0 ELSE
AAM[1,4]=193.0;
IF LAML LEQ 10  THEN AAM[2,1]=136.0 ELSE
IF LAML LEQ 20  THEN AAM[2,1]=123.0 ELSE
IF LAML LEQ 30  THEN AAM[2,1]=116.0 ELSE
IF LAML LEQ 40  THEN AAM[2,1]=111.0 ELSE
IF LAML LEQ 50  THEN AAM[2,1]=108.0 ELSE
AAM[2,1]=106.0;
IF LAML LEQ 10  THEN AAM[2,2]=176.0 ELSE
IF LAML LEQ 20  THEN AAM[2,2]=140.0 ELSE
IF LAML LEQ 30  THEN AAM[2,2]=125.0 ELSE
IF LAML LEQ 40  THEN AAM[2,2]=116.0 ELSE
IF LAML LEQ 50  THEN AAM[2,2]=111.0 ELSE
AAM[2,2]=111.0;
IF LAML LEQ 10  THEN AAM[2,3]=161.0 ELSE
IF LAML LEQ 20  THEN AAM[2,3]=133.0 ELSE
IF LAML LEQ 30  THEN AAM[2,3]=120.0 ELSE
IF LAML LEQ 40  THEN AAM[2,3]=111.0 ELSE
IF LAML LEQ 50  THEN AAM[2,3]=107.0 ELSE
AAM[2,3]=103.0;
IF LAML LEQ 10  THEN AAM[2,4]=233.0 ELSE
IF LAML LEQ 20  THEN AAM[2,4]=193.0 ELSE
IF LAML LEQ 30  THEN AAM[2,4]=176.0 ELSE
IF LAML LEQ 40  THEN AAM[2,4]=166.0 ELSE
IF LAML LEQ 50  THEN AAM[2,4]=161.0 ELSE
AAM[2,4]=161.0;
IF LAML LEQ 10  THEN AAM[3,1]=144.0 ELSE
IF LAML LEQ 20  THEN AAM[3,1]=129.0 ELSE
IF LAML LEQ 30  THEN AAM[3,1]=122.0 ELSE
IF LAML LEQ 40  THEN AAM[3,1]=117.0 ELSE
IF LAML LEQ 50  THEN AAM[3,1]=113.0 ELSE
AAM[3,1]=110.0;
IF LAML LEQ 10  THEN AAM[3,2]=121.0 ELSE
IF LAML LEQ 20  THEN AAM[3,2]=108.0 ELSE
IF LAML LEQ 30  THEN AAM[3,2]=102.0 ELSE
IF LAML LEQ 40  THEN AAM[3,2]=98.0  ELSE
IF LAML LEQ 50  THEN AAM[3,2]=96.0  ELSE
AAM[3,2]=93.0;
IF LAML LEQ 10  THEN AAM[3,3]=160.0 ELSE
IF LAML LEQ 20  THEN AAM[3,3]=138.0 ELSE
IF LAML LEQ 30  THEN AAM[3,3]=129.0 ELSE
IF LAML LEQ 40  THEN AAM[3,3]=122.0 ELSE
IF LAML LEQ 50  THEN AAM[3,3]=118.0 ELSE
AAM[3,3]=115.0;
IF LAML LEQ 10  THEN AAM[3,4]=184.0 ELSE
IF LAML LEQ 20  THEN AAM[3,4]=161.0 ELSE
IF LAML LEQ 30  THEN AAM[3,4]=151.0 ELSE
IF LAML LEQ 40  THEN AAM[3,4]=145.0 ELSE
IF LAML LEQ 50  THEN AAM[3,4]=141.0 ELSE
AAM[3,4]=141.0;
IF LAML LEQ 10  THEN AAM[4,1]=136.0 ELSE
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IF LAML LEQ 20  THEN AAM[4,1]=112.0 ELSE
IF LAML LEQ 30  THEN AAM[4,1]=101.0 ELSE
IF LAML LEQ 40  THEN AAM[4,1]=97.0  ELSE
IF LAML LEQ 50  THEN AAM[4,1]=97.0  ELSE
AAM[4,1]=97.0;
IF LAML LEQ 10  THEN AAM[4,2]=139.0 ELSE
IF LAML LEQ 20  THEN AAM[4,2]=122.0 ELSE
IF LAML LEQ 30  THEN AAM[4,2]=114.0 ELSE
IF LAML LEQ 40  THEN AAM[4,2]=109.0 ELSE
IF LAML LEQ 50  THEN AAM[4,2]=108.0 ELSE
AAM[4,2]=108.0;
IF LAML LEQ 10  THEN AAM[4,3]=149.0 ELSE
IF LAML LEQ 20  THEN AAM[4,3]=130.0 ELSE
IF LAML LEQ 30  THEN AAM[4,3]=121.0 ELSE
IF LAML LEQ 40  THEN AAM[4,3]=116.0 ELSE
IF LAML LEQ 50  THEN AAM[4,3]=115.0 ELSE
AAM[4,3]=115.0;
IF LAML LEQ 10  THEN AAM[4,4]=179.0 ELSE
IF LAML LEQ 20  THEN AAM[4,4]=148.0 ELSE
IF LAML LEQ 30  THEN AAM[4,4]=136.0 ELSE
IF LAML LEQ 40  THEN AAM[4,4]=128.0 ELSE
IF LAML LEQ 50  THEN AAM[4,4]=124.0 ELSE
AAM[4,4]=120.0;
 AAM[1,5]=AAM[1,4];  AAM[2,5]=AAM[2,4];  AAM[3,5]=AAM[3,4];
AAM[4,5]=AAM[4,4];  AAM[5,1]=AAM[4,1];  AAM[5,2]=AAM[4,2];
AAM[5,3]=AAM[4,3];  AAM[5,4]=AAM[4,4];  AAM[5,5]=AAM[4,4];
 K=0;
 FOR J=1 STEP 1 UNTIL 5 DO FOR I=1 STEP 1 UNTIL 5 DO BEGIN
A[I,J]=AAM[I,J];
IF PAK EQL 2   THEN A[I,J]=A[I,J]*.88 ELSE
IF PAK EQL 3   THEN A[I,J]=A[I,J]*.88;
K=K+1;  TERM[K]=PCT[I]*PCT[J]*  A[I,J];
    END;      A11=0;
     FOR K=1 STEP 1 UNTIL 25 DO A11=A11+TERM[K];
    K=0;
     FOR J=1 STEP 1 UNTIL 5 DO FOR I=1 STEP 1 UNTIL 5 DO BEGIN
K=K+1; TERM[K]= PCT[I]*PCT[J]*(  A[I,J]**2);      END; A22=0;
    FOR K=1 STEP 1 UNTIL 25 DO A22=A22+TERM[K];

    END CALA;

PROCEDURE       DELAY(LAML,A,B,C,D,E,W,AD,PAK);
REAL LAML,W,AD,               A,B,C,D,E;  INTEGER  PAK;
BEGIN
REAL     A1,A2,G,G1,S1,T,T1,T2,T3,T4,J1,J2,W0,W1,W2,  W21,R,F1,C1,RLEN,
       RALT,RRATING,A11,LAMT,LAMS,A22;
REAL ARRAY   RCF,CRLEN,ER,PCT[0:5],HSTURNO[0:10],F[0:25,0:25],
        FF[0:5,0:5];
INTEGER  P;
       RLEN=9500;
          P=3;HSTURNO[1]=3000;HSTURNO[2]=4500;HSTURNO[3]=6200;
           RALT=4800;
          PCT[1]=A;PCT[2]=B;PCT[3]=C;PCT[4]=D;PCT[5]=E;
          LAMS=2*LAML;   LAMT=LAML;
         CALRCF(RALT,RCF);
         CALA(LAML,PCT,A11,A22,PAK);
        CALER(RCF,RLEN,CRLEN,P,ER,HSTURNO);
        CALRRATING(CRLEN,ER,PCT,RRATING);
```

```
CALR(LAML,RRATING,R,PAK);
      CALC1(PCT,C1,PAK);
CALF1(PCT,F1,PAK);
CALT(LAMS,PCT,T,PAK);
 A1=3600/LAML;
 G1=A1-R-C1;
 A2=G1**2+A1**2;
 G=1/G1;
 S1=F1-C1;
 T1=EXP(G*S1);
 T2=EXP(-G*T);
 T3=1-T2;
 W21=A1*(T1-1)-S1;
 J1=A1*T1*T3;
 J2=J1*W21+T1*(A2*T3/2-A1*T*T2);
 T4=LAMT*J1/3600;
 W0=J2*LAMT/(3600*(1-T4));
 W1=A2/(2*A1)-G1;
AD=LAML*A22/(7200-2*LAML*AI1);
 W=W21+W1+W0;

END DELAY;
WRITE(EJECT);
WRITE('RUN NUMBER=',E);
 WRITE('INPUT DATA IMAGE');
            I=1;
            P=0;
 SEP=5000; EXT=1000; CLR=1000; LCTOL=10000;
READ(          ID,MIX[I],ACT[0,1],NOAC[1],ACT[0,2],NOAC[2],
                     ACT[0,3],NOAC[3],ACT[0,4],NOAC[4],
                     ACT[0,5],NOAC[5],DR1);
             P=P+1;
WRITE(PRINTER,   ID,MIX[I],ACT[0,1],NOAC[1],ACT[0,2],NOAC[2],
                     ACT[0,3],NOAC[3],ACT[0,4],NOAC[4],
                     ACT[0,5],NOAC[5],DR1OUT);
            IF ID NEQ 12 THEN GO TO ERR3;
            FOR L=1 STEP 1 UNTIL 11 DO
          BEGIN
         J=1;
            READ(ID    ,    CID[L,J],TAP[L],TMAX[L],LAMS[L],CTL[L],
              LSTOL[L],DR2);
IF LAMS[L] EQL 0 THEN LAMS[L]=1;
             P=P+1;
TMAX[L]=4;
     WRITE(PRINTER, ID,CID[L,J],TAP[L],TMAX[L],LAMS[L],CTL[L],
     LSTOL[L],DR2OUT);
       TMAX[L]=TMAX[L]*60;
            FOR J=1 STEP 1 UNTIL MIX[I] DO
            BEGIN
            READ(  ID,      CID[L,J],ACT[L,J],TPCT[L,J],ACCL[L,J],
              PCTOL[L,J],PSTOL[L,J],DR3);
             P=P+1;
WRITE(PRINTER,ID, CID[L,J],ACT[L,J],TPCT[L,J],ACCL[L,J],
    PCTOL[L,J],PSTOL[L,J],DR3OUT);
            END;
            PS[L]=0;
          FOR J=1 STEP 1 UNTIL MIX[I] DO
            IF ACCL[L,J] EQL 4 THEN PS[L]=PS[L]+TPCT[L,J];
```

```
            IF TAP[L] EQL 1 THEN
                BEGIN  A[L]=(LAMS[L]/2);B[L]=0; GO TO RWAY  END ELSE
            IF TAP[L] EQL 2 THEN
                BEGIN  A[L]=(LAMS[L]/4);B[L]=0; GO TO RWAY  END ELSE
            IF TAP[L] EQL 3 THEN
                BEGIN  B[L]=(((PS[L])*(LAMS[L]))/2);A[L]=((LAMS[L])/2
                 -B[L]);GO TO RWAY  END ELSE
            IF TAP[L] EQL 4 THEN
                BEGIN B[L]=(((PS[L])*(LAMS[L]))/4);
                  A[L]=LAMS[L]*(1-PS[L])/2.0; GO TO RWAY END ELSE
            IF TAP[L] EQL 5 THEN
                BEGIN B[L]=(((PS[L])*(LAMS[L]))/4);A[L]=(((LAMS[L])*
                  (1-PS[L]))/4);GO TO RWAY  END ELSE
            IF TAP[L] EQL 6 THEN
                BEGIN A[L]=0; B[L]=((LAMS[L])/2); GO TO RWAY  END ELSE
            GO TO ERR4;
     RWAY: PCT[L,1]=0.0; PCT[L,2]=0.0; PCT[L,3]=0.0;PCT[L,4]=0.0;
                PCT[L,5]=0.0;
                FOR J=1 STEP 1 UNTIL MIX[I] DO
             BEGIN
           IF ACCL[L,J] EQL 1 THEN PCT[L,1]=(TPCT[L,J]+PCT[L,1]) ELSE
           IF ACCL[L,1] EQL 2 THEN PCT[L,2]=(TPCT[L,J]+PCT[L,2]) ELSE
         IF ACCL[L,J] EQL 3 THEN PCT[L,3]=(TPCT[L,J]+PCT[L,3]) ELSE
         IF ACCL[L,J] EQL 4 THEN PCT[L,4]=(TPCT[L,J]+PCT[L,4]) ELSE
         IF ACCL[L,J] EQL 5 THEN PCT[L,5]=(TPCT[L,J]+PCT[L,5]) ELSE
                GO TO ERR1;
            END;
                N=0;
   F5:   N=N+1; AA=A[L]/N; IF A[L] LEQ 0 THEN
       BEGIN RWCTOL[L]=0; GO TO F6 END;
                DELAY(AA,PCT[L,1],PCT[L,2],PCT[L,3],PCT[L,4],
                PCT[L,5],GCDELAY[L],ACDELAY[L],CTL[L]);
IF GCDELAY[L] LSS 0.0 OR ACDELAY[L] LSS 0.0 THEN GO TO F20;
                IF GCDELAY[L] GTR ACDELAY[L]
                THEN WCMAX[L]=GCDELAY[L]
                ELSE WCMAX[L]=ACDELAY[L];
            IF WCMAX[L] LSS TMAX[L] THEN BEGIN RWCTOL[L]=N; GO TO F6
                  END ELSE
F20: IF N GTR 12 THEN GO TO ERR2 ELSE GO TO F5;
          F6:   M=0;
          F8:   M=M+1;
              BB=B[L]/M; IF B[L] LEQ 0 THEN
          BEGIN  RWSTOL[L]= 0; GO TO F7 END;
                DELAY(BB   ,PCT[L,1],PCT[L,2],PCT[L,3],PCT[L,4],
                PCT[L,5],GSDELAY[L],ASDELAY[L],CTL[L]);
IF GSDELAY[L] LSS 0.0 OR ASDELAY[L] LSS 0.0 THEN GO TO F21;
                IF GSDELAY[L] GTR ASDELAY[L]
                THEN WSMAX[L]=GSDELAY[L]
                ELSE WSMAX[L]=ASDELAY[L];
             IF WSMAX[L] LSS TMAX[L] THEN BEGIN RWSTOL[L]=M; GO TO F7
                  END ELSE
F21: IF M GTR 8 THEN GO TO ERR2 ELSE GO TO F8;
   F7: IF (TAP[L] EQL 1 OR TAP[L] EQL 2) AND (PS[L] NEQ 0.0)
                    THEN BEGIN
                         GSDELAY[L]=GCDELAY[L];
                         ASDELAY[L]=ACDELAY[L] END;
IF TAP[L] EQL 1 THEN
BEGIN
```

```
                AREA(RWCTOL[L],RWSTOL[L],LCTOL,LSTOL[L],SEP,CLR,EXT,
                CTOTAREA[L],STOTAREA[L],CTOTEX[L],STOTEX[L],
CAVETAXI[L],SAVETAXI[L]) ;
TOTLINFTRUN[L]=RWCTOL[L]*LCTOL;
 END ELSE
            IF TAP[L] EQL 2 THEN
              BEGIN
                AREA(RWCTOL[L],RWSTOL[L],LCTOL,LSTOL[L],SEP,CLR,EXT,
                CTOTAREA[L],STOTAREA[L],CTOTEX[L],STOTEX[L],
                CAVETAXI[L],SAVETAXI[L]);
                CTOTAREA[L]=2.0*CTOTAREA[L];
                CTOTEX[L]=2.0*CTOTEX[L]    ;
TOTLINFTRUN[L]=2*RWCTOL[L]*LCTOL;
               END ELSE
            IF TAP[L] EQL 3 THEN
BEGIN
                AREA(RWCTOL[L],RWSTOL[L],LCTOL,LSTOL[L],SEP,CLR,EXT,
                CTOTAREA[L],STOTAREA[L],CTOTEX[L],STOTEX[L],
CAVETAXI[L],SAVETAXI[L]) ;
TOTLINFTRUN[L]=RWCTOL[L]*LCTOL;
 END ELSE
            IF TAP[L] EQL 4 THEN
              BEGIN
AREA(RWCTOL[L],RWSTOL[L],LCTOL,LSTOL[L],SEP,CLR,EXT,
CAREA1,SAREA1,CEXAREA1,SEXAREA1,CTAXI1,STAXI1);
AREA(0,RWSTOL[L],LCTOL,LSTOL[L],SEP,CLR,EXT,
CAREA2,SAREA2,CEXAREA2,SEXAREA2,CTAXI2,STAXI2);
                CTOTAREA[L]=CAREA1+CAREA2;
                STOTAREA[L]=SAREA1+SAREA2;
                CTOTEX[L]=CEXAREA1+CEXAREA2;
                STOTEX[L]=SEXAREA1+SEXAREA2;
CAVETAXI[L]=CTAXI1;
SAVETAXI[L]=(STAXI1+STAXI2)/2.0;
TOTLINFTRUN[L]=RWCTOL[L]*LCTOL;
              END ELSE
            IF TAP[L] EQL 5 THEN
                BEGIN
                AREA(RWCTOL[L],RWSTOL[L],LCTOL,LSTOL[L],SEP,CLR,EXT,
                CTOTAREA[L],STOTAREA[L],CTOTEX[L],STOTEX[L],
                CAVETAXI[L],SAVETAXI[L]);
                CTOTAREA[L]=2.0*CTOTAREA[L];
                STOTAREA[L]=2.0*STOTAREA[L];
                CTOTEX[L]=2.0*CTOTEX[L];
                STOTEX[L]=2.0*STOTEX[L];
TOTLINFTRUN[L]=RWCTOL[L]*2.0*LCTOL;
             END ELSE
            IF TAP[L] EQL 6 THEN
BEGIN
                AREA(RWCTOL[L],RWSTOL[L],LCTOL,LSTOL[L],SEP,CLR,EXT,
              CTOTAREA[L],STOTAREA[L],CTOTEX[L],STOTEX[L],
CAVETAXI[L],SAVETAXI[L]) ;
 END ELSE
            GO TO ERR7
              END;
 WRITE('OUTPUT DATA IMAGE');
          FOR J=1 STEP 1 UNTIL MIX[I] DO TOTOPS[J]=0.0;
          FOR J=1 STEP 1 UNTIL MIX[I] DO
             FOR L=1 STEP 1 UNTIL 11 DO
```

```
BEGIN
            TOTOPS[J]=TOTOPS[J]+TPCT[L,J]*LAMS[L]/2.0;
IF TOTOPS[J] EQL 0 THEN TOTOPS[J]=1;
END;
        FOR J=1 STEP 1 UNTIL MIX[I] DO SUM[J]=0.0;
        FOR J=1 STEP 1 UNTIL MIX[I] DO
           FOR L=1 STEP 1 UNTIL 11 DO
              IF ACCL[L,J] EQL 4 OR ACCL[L,J] EQL 5
                 THEN SUM[J]=SUM[J]+LAMS[L]*TPCT[L,J]*GSDELAY[L]/2.0
              ELSE SUM[J]=SUM[J]+LAMS[L]*TPCT[L,J]*GCDELAY[L]/2.0;
           FOR J=1 STEP 1 UNTIL MIX[I] DO
             AVEGRDELAY[J]=SUM[J]/TOTOPS[J]/3600.0;
        FOR J=1 STEP 1 UNTIL MIX[I] DO SUM[J]=0.0;
        FOR J=1 STEP 1 UNTIL MIX[I] DO
           FOR L=1 STEP 1 UNTIL 11 DO
              IF ACCL[L,J] EQL 4 OR ACCL[L,J] EQL 5
THEN SUM[J]=SUM[J]+LAMS[L]*TPCT[L,J]*SAVETAXI[L]
ELSE SUM[J]=SUM[J]+LAMS[L]*TPCT[L,J]*CAVETAXI[L];
        FOR J=1 STEP 1 UNTIL MIX[I] DO
AVEGRDELAY[J]=SUM[J]/TOTOPS[J]/3600.0+AVEGRDELAY[J];
        FOR J=1 STEP 1 UNTIL MIX[I] DO SUM[J]=0.0;
        FOR J=1 STEP 1 UNTIL MIX[I] DO
           FOR L=1 STEP 1 UNTIL 11 DO
              IF ACCL[L,J] EQL 4 OR ACCL[L,J] EQL 5
              THEN SUM[J]=SUM[J]+LAMS[L]*TPCT[L,J]*ASDELAY[L]/2.0
                 ELSE SUM[J]=SUM[J]+LAMS[L]*TPCT[L,J]*ACDELAY[L]/2.0 ;
         FOR J=1 STEP 1 UNTIL MIX[I] DO
             AVEAIRDELAY[J]=SUM[J]/TOTOPS[J]/3600.0;
          FOR L=1 STEP 1 UNTIL 11 DO BEGIN
             ACRES=0.000023;  UU=CTOTAREA[L]*ACRES;
           VV=STOTAREA[L]*ACRES; WW=STOTEX[L]*ACRES;
              XX=CTOTEX[L]*ACRES;
              WRITE(PUNCH,    CID[L,1] ,UU,VV,WW,XX,TOTLINFTRUN[L],
               RWSTOL[L],TM1);
              WRITE(PRINTER , CID[L,1],UU,VV,WW,XX,TOTLINFTRUN[L],
               RWSTOL[L],TM1);
              END;
              FOR L=1 STEP 1 UNTIL 11 DO  BEGIN
              U=GSDELAY[L]/60;    V=ASDELAY[L]/60;
     W=SAVETAXI[L]/60;       X=GCDELAY[L]/60;
         Y=ACDELAY[L]/60;           Z=CAVETAXI[L]/60;
          WRITE(PUNCH,    U,V,W,X,Y,Z,CID[L,1],EF);
          WRITE(PRINTER, U,V,W,X,Y,Z,CID[L,1],EF); END;
          FOR J=1 STEP 1 UNTIL MIX[I] DO   BEGIN
            WRITE (PUNCH    ,ACT[1,J],AVEGRDELAY[J],AVEAIRDELAY[J],AC);
            WRITE (PRINTER ,ACT[1,J],AVEGRDELAY[J],AVEAIRDELAY[J],AC)
 END;
              FOR L=1 STEP 1 UNTIL 11 DO  BEGIN
            ACRES=0.000023;  UU=CTOTAREA[L]*ACRES;
          VV=STOTAREA[L]*ACRES; WW=STOTEX[L]*ACRES;
              XX=CTOTEX[L]*ACRES;
              WRITE(PUNCH,     CID[L,1],UU,VV,WW,XX,TOTLINFTRUN[L],
            RWSTOL[L],TM2);
              WRITE(PRINTER , CID[L,1] ,UU,VV,WW,XX,TOTLINFTRUN[L],
            RWSTOL[L],TM2);
 END;
        WRITE(PRINTER,TERMHEADA);
        WRITE(PRINTER,TERMHEADB);
```

```
      WRITE(PRINTER,TERMHEADC);
         FOR  L=1 STEP 1 UNTIL 11 DO BEGIN
               ACRES=0.000023;  UU=CTOTAREA[L]*ACRES;
            VV=STOTAREA[L]*ACRES;  WW=STOTEX[L]*ACRES;
                XX=CTOTEX[L]*ACRES;
 WRITE(PRINTER,CID[L,1],VV,UU,WW,XX,TOTLINFTRUN[L],RWSTOL[L],TERMDATA)
             END;
         WRITE(PRINTER,EFFHEADA);
         WRITE(PRINTER,EFFHEADB);
         WRITE(PRINTER,EFFHEADC);
         FOR  L=1 STEP 1 UNTIL 11 DO BEGIN
       W=SAVETAXI[L]/60;      X=GCDELAY[L]/60;
               U=GSDELAY[L]/60;    V=ASDELAY[L]/60;
            Y=ACDELAY[L]/60;          Z=CAVETAXI[L]/60;
           WRITE(PRINTER,EFFDATA,CID[L,1],V,Y,U,X,W,Z )  END;
         WRITE(PRINTER,ACHEADA);
         WRITE(PRINTER,ACHEADB);
   FOR J=1 STEP 1 UNTIL MIX[I] DO
       WRITE(PRINTER,ACT[I,J],AVEGRDELAY[J],AVEAIRDELAY[J],ACDATA);
BEGIN

REAL THRES,C;
REAL ARRAY ACOST[0:11],GCOST[0:11],MCOST[0:11],TCOST[0:11];
INTEGER PKG,TNAC,Z,ZZ,D,J;
   FORMAT F1('28  ',I12,A1);
FOR J=1 STEP 1 UNTIL 5 DO
TNAC=TNAC+NOAC[J];
PKG=CTL[1];
FOR Z=1 STEP 1 UNTIL 3 DO
BEGIN
TCOST[Z]=0.0;
GCOST[Z]=0.0
END;
FOR Z=1 STEP 1 UNTIL 11 DO
BEGIN
IF TAP[Z] EQL 1 OR TAP[Z] EQL 3 OR TAP[Z] EQL 6
THEN ZZ=1
ELSE IF TAP[Z] EQL 2 OR TAP[Z] EQL 4
THEN ZZ=2
ELSE ZZ=3;
THRES=(ZZ*50000)/(365*24);
IF LAMS[Z] GEQ THRES
THEN BEGIN
TCOST[1]=TCOST[1]+ZZ*2.558;
TCOST[2]=TCOST[2]+ZZ*3.010;
TCOST[3]=TCOST[3]+ZZ*3.010;
MCOST[1]=MCOST[1]+ZZ*.641;
MCOST[2]=MCOST[2]+ZZ*.661;
MCOST[3]=MCOST[3]+ZZ*.666;
END
ELSE BEGIN
TCOST[1]=TCOST[1]+ZZ*2.256;
TCOST[2]=TCOST[2]+ZZ*2.708;
TCOST[3]=TCOST[3]+ZZ*2.708;
MCOST[1]=MCOST[1]+ZZ*.559;
MCOST[2]=MCOST[2]+ZZ*.579;
MCOST[3]=MCOST[3]+ZZ*.584;
END
```

```
END;
ACOST[1]=.015;
ACOST[2]=.026;
ACOST[3]=.087;
GCOST[1]=13.22;
GCOST[2]=22.378;
GCOST[3]=22.378;
MCOST[1]=MCOST[1]+1.094;
MCOST[2]=MCOST[2]+1.5;
MCOST[3]=MCOST[3]+1.5;
C=(TCOST[PKG]+ACOST[PKG]*TNAC+GCOST[PKG])*1.9+MCOST[PKG]*27.71;
D=C*1000000;
DOL=D;
WRITE('D=',D);
WRITE('CONTROL PKG=',PKG);
WRITE('CONTROL COST=',D);
WRITE(PUNCH,F1,D);

END;
FOR L=1 STEP 1 UNTIL 11 DO BEGIN
IF TAP[L] EQL 1 THEN BEGIN
STOLAP[L]=0  ;
CTOLAP[L]=1  ;
STCTAP[L]=0;
END ELSE IF TAP[L] EQL 2 THEN BEGIN
STOLAP[L]=0  ;
CTOLAP[L]=2  ;
STCTAP[L]=0;
END ELSE IF TAP[L] EQL 3 THEN BEGIN
STOLAP[L]=0  ;
CTOLAP[L]=0  ;
STCTAP[L]=1;
END ELSE IF TAP[L] EQL 4 THEN BEGIN
STOLAP[L]=1;
CTOLAP[L]=0;
STCTAP[L]=1;
END ELSE IF TAP[L] EQL 5 THEN BEGIN
STOLAP[L]=1;
CTOLAP[L]=1;
STCTAP[L]=1;
END ELSE
BEGIN
STOLAP[L]=1;
CTOLAP[L]=0;
STCTAP[L]=0;
END;
END;
WRITE(EJECT);
WRITE(STAR);
WRITE(RM1,E,TMAX[1],CTL[1],DOL);
WRITE(STAR);
WRITE(                                                              '
*  *                    * NUMBER  *          *          *TOTAL*   HOLD TIME
 [MIN] *   TAXI  *       *  *'
);
WRITE(                                                              '
*C * NUMBER OF AIRPORTS* RUNWAYS *  TOTAL  *  EXCESS *FEET *************
********   TIME  *OPS  *C *'
```

```
);
WRITE(                                                                  '
*I *                  *   PER   *  ACRES  *   ACRES *CTOL *              *
       *  [MIN]  * PER   *I *'
);
WRITE(                                                                  '
*T *                  * AIRPORT *          *           *RWAY *  AIR      *
GROUND *          * HOUR *T *'
);
WRITE(                                                                  '
*Y ******************************************************       *************
*****************          *Y *'
);
WRITE(STAR);
WRITE(                                                                  '
*  *STOL*CTOL*STOL/CTOL*STOL*CTOL*STOL*CTOL*STOL*CTOL*      *STOL*CTOL*ST
OL*CTOL*STOL*CTOL*          *  *'
);
FOR L=1 STEP 1 UNTIL 11 DO BEGIN
VV=STOTAREA[L]*ACRES;
UU=CTOTAREA[L]*ACRES;
WW=STOTEX[L]*ACRES;
XX=CTOTEX[L]*ACRES;
U=GSDELAY[L]/60;
V=ASDELAY[L]/60;
W=SAVETAXI[L]/60;
X=GCDELAY[L]/60;
Y=ACDELAY[L]/60;
Z=CAVETAXI[L]/60;
WRITE(RM2,CID[L,1],STOLAP[L],CTOLAP[L],STCTAP[L],RWSTOL[L],RWCTOL[L],
VV,UU,WW,XX,TOTLINFTRUN[L],V,Y,U,X,W,Z,LAMS[L]);
END;
WRITE(STAR);
WRITE(                                                                  '
************************'
);
WRITE(                                                                  '
* A/C *     *GROUND* AIR*'
);
WRITE(                                                                  '
*IDENT*  NO.* TIME *HOLD*'
);
WRITE(                                                                  '
*     *     * [HRS]*TIME*'
);
FOR J=1 STEP 1 UNTIL MIX[I] DO
WRITE(RM3,ACT[0,J],NOAC[J],AVEGRDELAY[J] ,AVEAIRDELAY[J]);
WRITE(                                                                  '
************************'
);
GO TO FINAL;
     ERR1: WRITE(PRINTER,FMT1);
     GO TO FINISH;
     ERR2: WRITE(PRINTER,FMT2);
     GO TO FINISH;
     ERR3: WRITE(PRINTER,FMT3);
     GO TO FINISH;
     ERR4: WRITE(PRINTER,FMT4);
```

```
      GO TO FINISH;
      ERR7: WRITE(PRINTER,FMT7);
      GO TO FINISH;
 FINISH: FOR Q=P STEP 1 UNTIL (MIX[I]+1)*11  DO
                 READ(FMT,NOTH);

 FINAL: END;
 END.
```

APPENDIX 6-C

NATIONAL AIRSPACE SYSTEM (NAS) DESCRIPTION

The automation of the NAS ATC System will take place at both terminals and enroute facilities. The present automation program, NAS En Route Stage A, concerns only the en route portion of the NAS. This automation will be followed by Stages B, C and others as required.

The NAS evolved from four needs identified by the FAA's System Design Team:

(1) Need for increased traffic handling capability and efficient movement of air vehicles thus reducing traffic delays.

(2) Need to maintain or increase safety with increased traffic handling capability.

(3) Need to simplify control process.

(4) Need to provide system growth potential.

The system goals of NAS were outlined as follows:

(1) Provide automation features for easy transfer and accurate processing and up dating of flight information.

(2) Provide automatic display of altitude or flight level information with aircraft positions.

(3) Provide automation aids for establishing and maintaining radar identification of aircraft in the system.

(4) Provide a computer processing capability to serve as the basis for implementation of subsequent automation improvement in ATC.

The goals of NAS En Route Stage A are being provided through the following capabilities:

(1) Automatically and manually initiate computer program tracking.

(2) Bright display of alphanumeric and radar data.

(3) Entry and processing of flight plan information.

(4) Flight progress strip printing at the appropriate sector postion.

(5) Provision for entering and receiving new and revised flight data (updates) at all operating positions.

(6) Intersector coordination through computer-generated alpha-numeric displays both plan-view and tabular.

(7) Interfacility coordination through the use of computer transmitted data.

(8) Computer generated displays of geographic and weather data.

(9) Provision for automatic computer initiated hand off capability with provision for manual hand off interrupt.

APPENDIX 6-D

SAFETY CONSIDERATIONS

STATISTICS

The concern for safety in the design of an air traffic control system was of paramount importance. However, the measures of safety and prediction of safety levels are often disputed.

Most statistics regarding safety levels (accidents, fatalities, etc.) are maintained with reference to the passenger mile. But, it does not seem reasonable that this reflects a true measure of risk. Statistics indicate that an increased percent of total accidents take place in the HUB area during landing and take off (See Fig. 6-D-1). Therefore, the level of danger is higher during take off and landing. Relating risk to take off's thus appears to be a more relevant indicator of degree of danger (See Figures 6-D-1, 6-D-2 and 6-D-3).

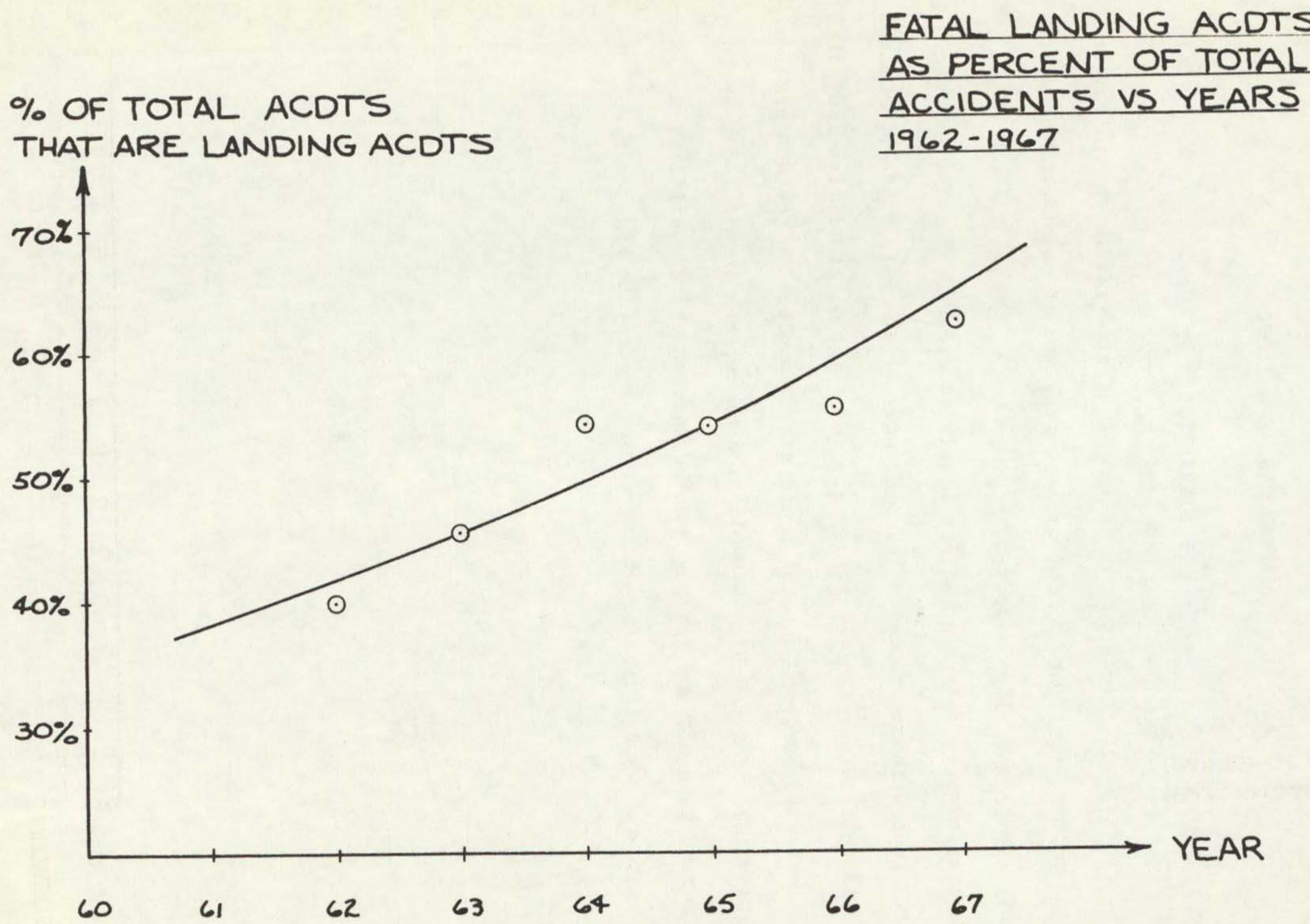
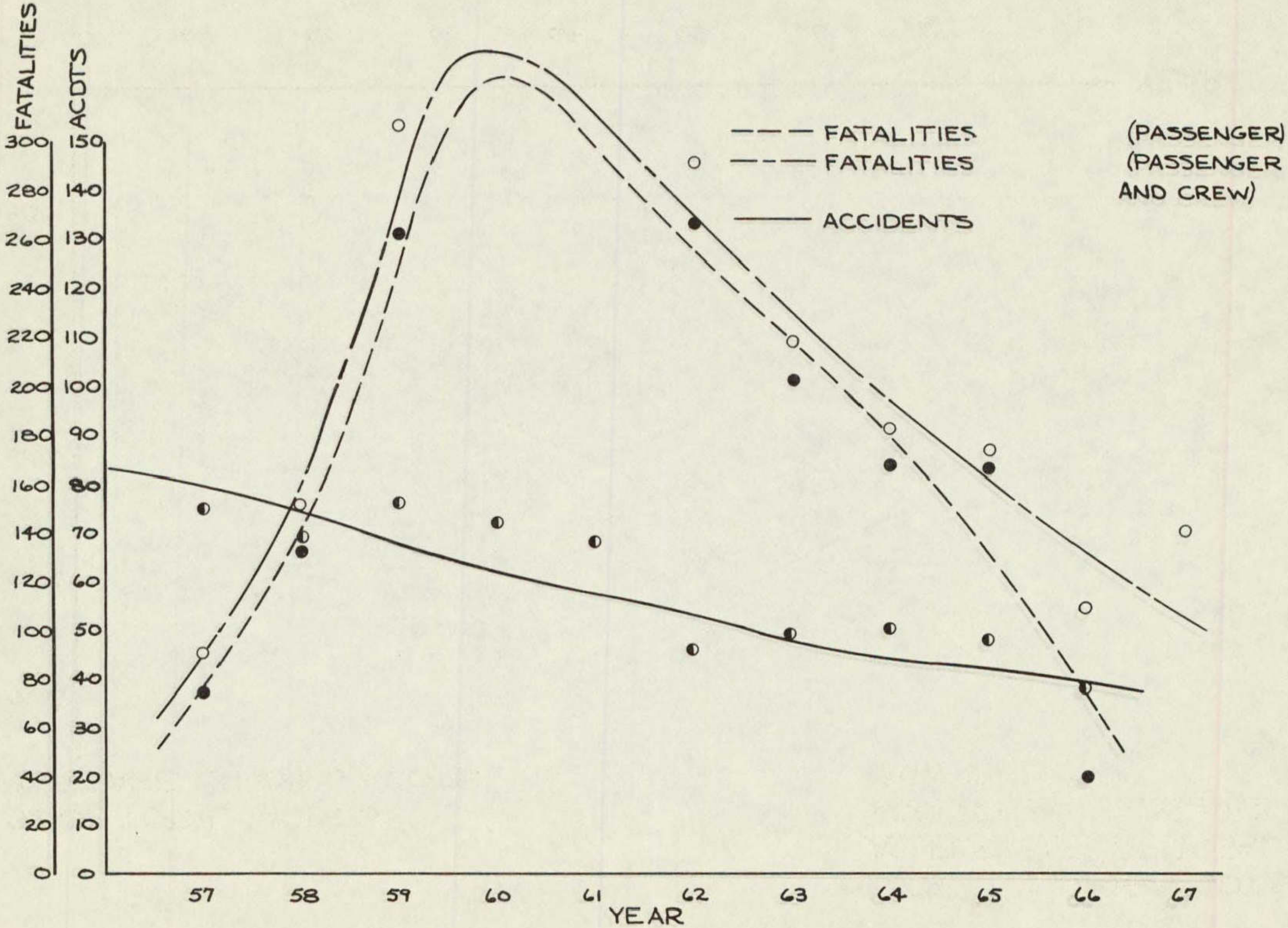
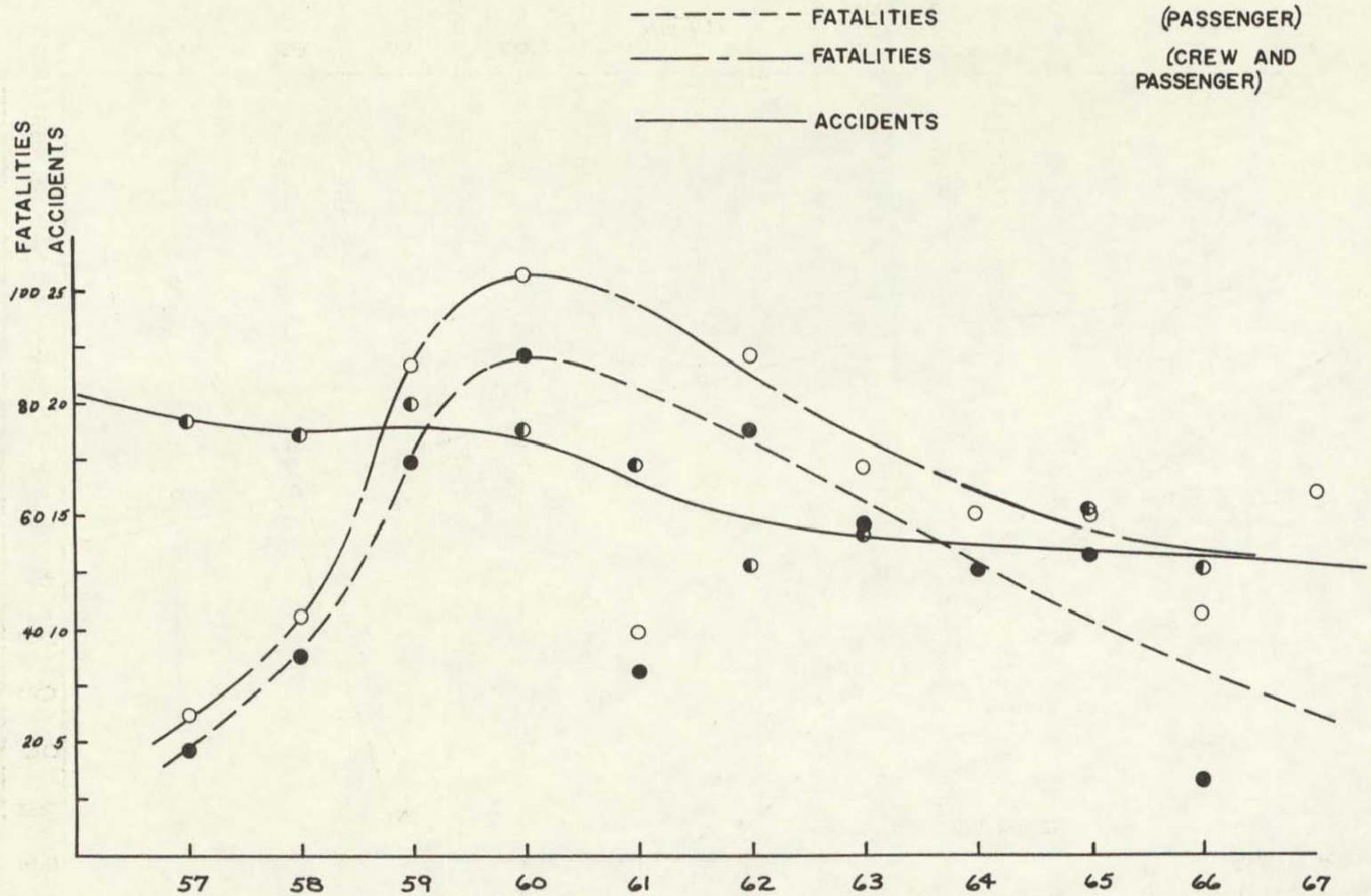

FATAL LANDING ACDTS
AS PERCENT OF TOTAL
ACCIDENTS VS YEARS
1962-1967
% OF TOTAL ACDTS
THAT ARE LANDING ACDTS
70%
60%
50%
40%
30%
YEAR
60
61
62
63
64
65
66
67

Figure 6-D-1



LANDING ACCIDENT STATISTICS

Figure 6-D-2



TAKE-OFF ACCIDENT STATISTICS

Figure 6-D-3

APPENDIX 6-E

PILOT WARNING INSTRUMENTS AND COLLISION AVOIDANCE SYSTEMS

6-E-1 General

Much industry and government work has been concentrated on collision avoidance systems and pilot warning indicators since the Air Transport Association (ATA) first asked for industrial proposals on collision avoidance systems in 1955. The FAA has assumed the responsibility of coordinating these efforts and has established the Collision Prevention Advisory Group (COPAG).

Since 1955 many systems have been proposed, built and tested. However, no system has met universal acceptance. This report describes some of the systems that have been proposed and the advantages and disadvantages of the system.

Two terms have come into usage to distinguish between two subclasses of collision avoidance systems. The term Pilot (Proximity) Warning Instruments (Indicators) or PWI refer to a class of devices that warn the pilot of nearby aircraft. A PWI is intended for use during VFR conditions since visual contact is still required by the pilot in order to avoid collision. A PWI might be a red light on the instument panel that flashes when another aircraft is within five miles, or in addition indicate the range and bearing of the intruder. However, the device could not distinguish between a collision threat and a safe miss.

Collision Avoidance Systems (CAS) have come to mean a class of more sophisticated devices that would prevent collision regardless of whether an intruder could be seen or not. This device would tell the pilot what avoidance maneuver

to make or perhaps automatically initiate an avoidance maneuver. Obviously it is desirable for the device to be able to distinguish between safe passes and emergency situations.

Also CAS and PWI are classified as being cooperative or self sufficient. The cooperative system requires all aircraft to carry some type of equipment which permits detection by other aircraft. In the self sufficient systems, no special equipment is required in order to detect intruding aircraft.

6-E-2 Proposed CAS and PWI System

Many CAS and PWI systems have been proposed since 1955. This section considers five basic principles of operation that are considered promising. All of the systems found in the literature were applications of these five basic principles.

6-E-2.1 Infrared Devices

A number of different infrared systems have been proposed. The main attraction for infrared devices is that they are inexpensive. However, it has been difficult to achieve the range and accuracy needed for adequate warning. All aircraft do emit in the infrared spectrum but it is difficult to detect particularly in sunlight when a large amount of background infrared emission is present. Attempts have been made to distinguish aircraft emission by detecting the pulsating emission of the piston engine; however, this was an earlier technique and has become obsolete with the advent of turbo prop and jet aircraft.

It has been fairly well established that self sufficient infrared systems can only provide a very limited amount of protection [11]. Cooperative infrared systems hold a greater possibility. In particular, a high intensity light is used to enhance the target. A cooperative system has been proposed [8] that has a range of 2 to 5 miles, and relative azimuth and elevation accuracies

within $\pm 5\%$. At a moderate closing velocity of 600 mph the pilot has 20 to 50 seconds to locate the intruder and manuever if collision is a threat.

6-E-2.2 Transponders

Transponders are cooperative systems that would require every aircraft to carry ar least a transponder. More fully equipped aircraft would carry equipment that would evaluate the situation and the avoidance maneuver would have to be implemented by the fully equipped aircraft.

The transponder is a device that responds to an interrogation signal of another aircraft. This system has many aspects of radar except that instead of depending on reflected signals, the target transmits a signal. The transponder signal may also be coded with the barometric altitude which is used to evaluate actual collision threats, i.e. aircraft at the same altitude.

In the Bendix system [15] the range is determined from a ground bouncing technique. The phase shift of the direct transponder signal and phase shift reflected from the ground is a function of the range and the altitude. Since the altitude is known, the range can be determined. The closing velocity can be determined by measuring the change in range over time. The doppler frequency shift cannot be easily used with this system since it would require extremely accurate calibration of the transponder signal. The direction of the intruder can be obtained by the direction of the antenna when the inerrogation signal was sent.

A Motorola system sends interrogator signals with altitude coding. Aircraft with altitudes within 1000 feet respond. The bearing is determined by comparing the phase shift of signals from three different antennas.

The Air Line Pilots Association have been studying a transponder CAS [17]. They estimate that a fully equipped, fully protected aircraft would have equip-

ment costing about $5000. All aircraft would be required to carry equipment costing $50 to $100.

6-E-2.3 Time/Frequency Systems

The term time/frequency refers to several systems that require frequency accuracy in the range of 1 part in 10^8. These frequencies in turn operate "clocks." Each aircraft is assigned a time slot in which to transmit a signal. An aircraft receiving the signal determines the range knowing when the time slot began and when the signal was received. This would correspond to about 1000 ft. per microsec. The closing velocity is determined by the doppler shift of the frequency. Coded barometric altitudes can also be transmitted.

The McDonnel EROS [16] system is a time/frequency that has been used by military aircraft. Each unit costs about $25,000 and weighs 30 pounds. In order to hold unit costs down, crystal oscillators are used which require frequent updating to correct for oscillator drift. Ground stations are used as master clocks to synchronize onboard clocks. These ground stations would have to be constructed at intervals of three or four hundred miles.

6-E-2.4 Continuous Wave

One recent development made by Langley Research Center is an open access C. W. CAS [7]. This system avoids the high cost of impulse type transmitter and receivers.

The protected aircraft concisely transmits two signals at different frequencies. The intruder receives the two signals and transmits the difference of the two frequencies. The difference in signal is received by the protected aircraft and compared to the difference of the transmitted frequencies for the doppler shift. The range is determined within 33% by the strength of the received signal.

6-E-2.5 Cockpit Display

This system presents a cockpit display of all aircraft in the area as transmitted from fround locating stations. A very simple version of this system would be a portable TV in the cockpit and a TV camera monitoring the ground controllers screen. The problem with the wide spread use of this simplified system is that the band width of the TV signal is too large. A slow scan TV might bring the band width within tolerable limits.

Another approach is to transmit coded locations. The onboard display would be a cathode ray tube similar to a radar screen. Transponsers would be used that allowed the ground station to determine and code the altitude of each aircraft. When the ground station would transmit the coded data, the outboard receiver would select and display only coded altitudes within a certain range of its own. This system could also be used for navigation.

6-E-3.1 Military Requirements

The largest percentage of military midair collisions occur among associated aircraft. For example two thirds of the midair collisions of Navy aircraft occur among aircraft that are operating together [3]. These collisions occur during tranining missions and during formation flying where each pilot is aware of the presence of the other aircraft [2]. High closing rates also present a problem to Air Force and Navy aircraft. Thus the military requires a fairly sophisticated system that could operate while aircraft are in formation and would automatically initiate an avoidance manuever when an actual collision course is detected.

6-E-3.2 Air Carrier Requirements

The primary difference between the military requirements and the air carrier requirements is that the air carriers do not operate in close formation. In addition, the closing rates for most of the air carriers are

not as high as those of military aircraft. The air carriers do desire a sophisticated CAS that would act as a safeguard when ATC has failed to provide separation. Most air carrier operators feel that a good CAS would require a cooperative system. Thus, some legislation would be required to implement such a system. ALPA feels that a cooperative system on all aircraft is not possible in the near future because the cost of the equipment available is too high for most owners [7]. However, it is felt that an inexpensive PWI could be used until an acceptable CAS is developed that would greatly reduce the risk of midair collisions.

6-E-3.3 General Aviation Requirements

The ALPA [5] whose members fly 98% of the aviation fleet desires a simple device that would alert pilots to other aircraft operating in the area. None of the present CAS are acceptable to general aviation operators because the equipment required for complete protection is much too expensive. In addition, the equipment that would have to be carried on board would provide protection for only a small percentage of aircraft operating.

APPENDIX 6-E

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APPENDIX 7-A

7-A-1 Reference Travel Time

Reference Travel Time (Reference Time) is based on the expected travel time of the air passenger in 1969. The relationship between the expected travel time and distance is shown in Figure 7-A-1. The elasticity of the travel time is the "percent change in the amount of travel time to percent time differential." This elasticity has the value of 0.3 [1]. Thus, a one percent increase in travel time would decrease the Revenue Passenger Miles (RPM) by 0.3. The effectiveness function for flight time (EFT) is:

$$\mathrm{EFT} = \left[\frac{\text{reference time}}{\text{actual time}}\right]^{0.3}$$

7-A-2 Fare Elasticity and Reference Fare [2]

The fare elasticity depends largely on the purpose of travel and has a value of 0.1 for business travel and 1.4 for non-business travel. This is based on estimates resulting from discussions with airline planning and marketing personnel. Assuming a 70-30 percent split of business and non-business travelers the overall elasticity is 0.45.

The elasticity of the fare is defined as the "percent change in amount of travel to percent fare differential." This elasticity has the value of 0.45, as discussed above.

This leads to the effectiveness function for the fare (EFFA):

$$\mathrm{EFFA} = \left[\frac{\text{reference fare}}{\text{actual fare}}\right]^{0.45}$$

The reference fare is computed from the 1969 air fares and the average cost for transportation to/from the airport, as shown in Figure 7-A-2. Due to time constraints it was necessary to omit this from the

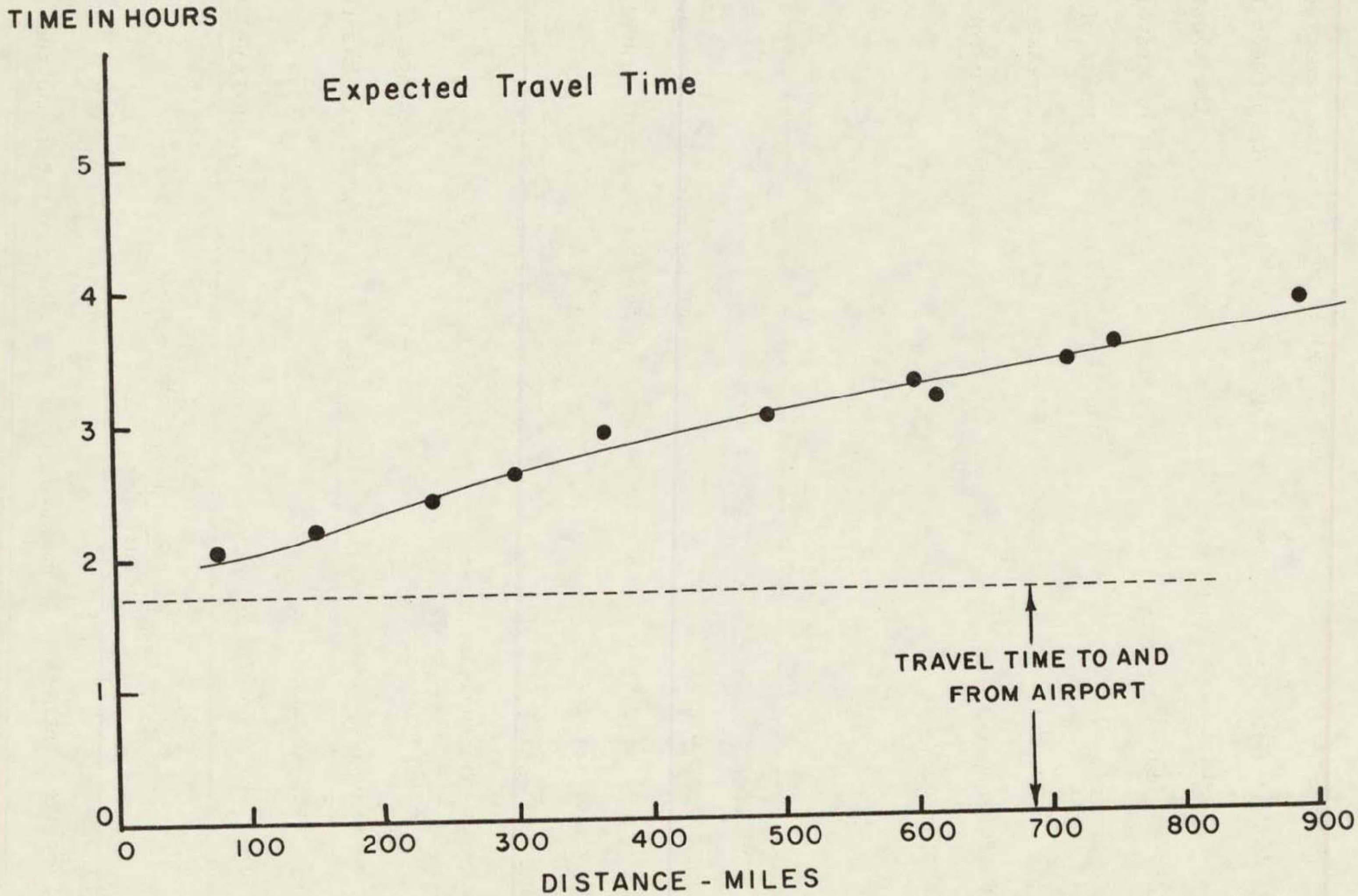
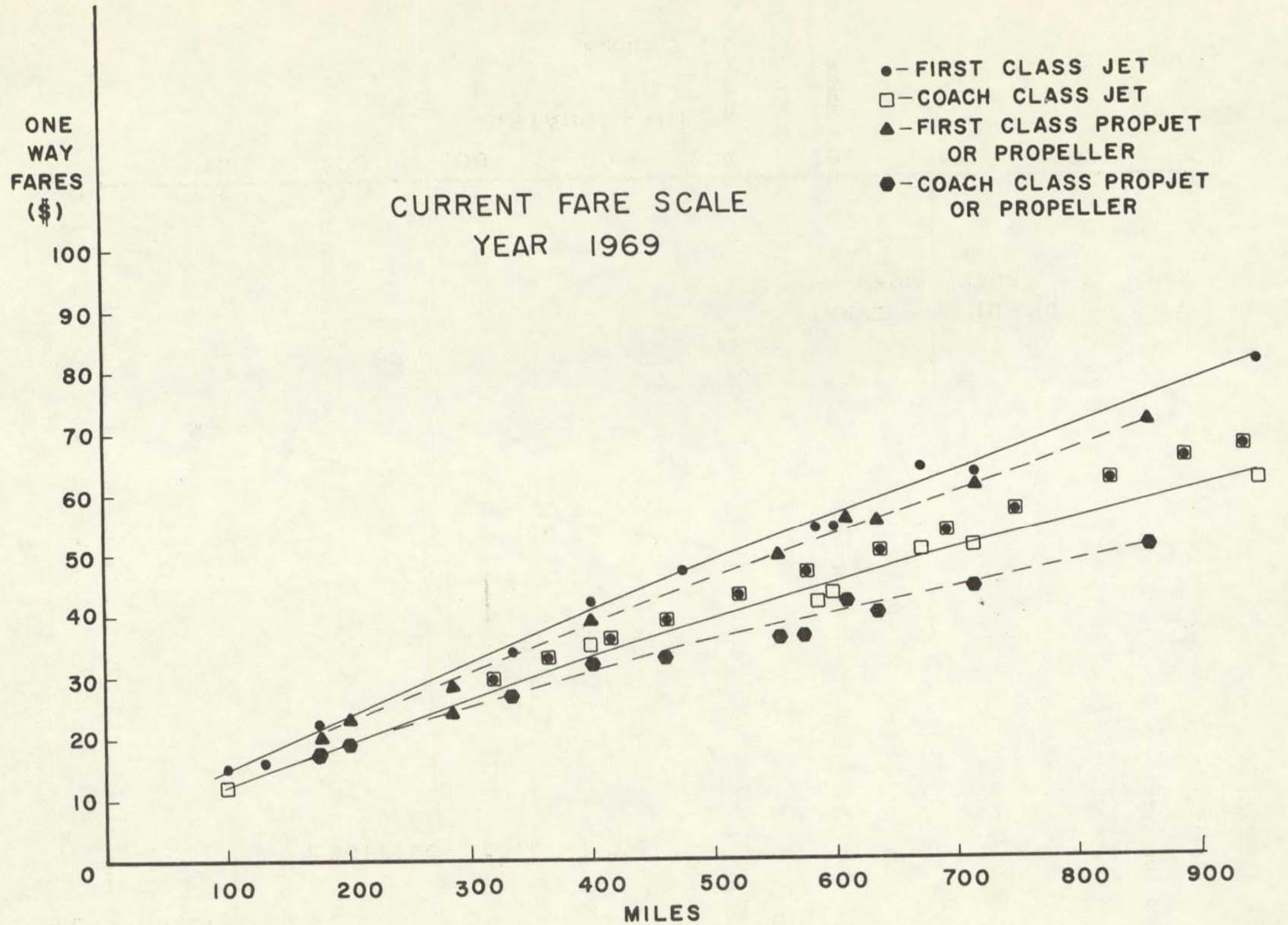

TIME IN HOURS
Expected Travel Time
5
4
3
2
1
0
TRAVEL TIME TO AND
FROM AIRPORT
0
100
200
300
400
500
600
700
800
900
DISTANCE - MILES

Figure 7-A-1



ONE WAY FARES ($)
CURRENT FARE SCALE
YEAR 1969
• - FIRST CLASS JET
□ - COACH CLASS JET
▲ - FIRST CLASS PROPJET OR PROPELLER
⬢ - COACH CLASS PROPJET OR PROPELLER
0
10
20
30
40
50
60
70
80
90
100
100
200
300
400
500
600
700
800
900
MILES

Figure 7-A-2

final model.

7-A-3 Frequency

Figure 7-A-3 illustrates the effect of flight frequency on passenger demand for service, taking into account the variations in the competitive ground transportation travel time. On the basis of this figure, one can compute the percent of the total number of potential air passengers that will seek air service for any flight frequency per day, given the distance traveled.

The total number of potential air passengers are those who would fly if these were a continuous "conveyor" of seats between the origin and destination. Since continuous (conveyor) air service is not provided, some potential passenger will use a surface mode because it is more convenient for them to do so. For a given surface travel distance, the percent of potential airline passengers that will seek service can be computed for any given frequency.

The example of a high demand, short distance market of Figure 7-A-3 shows that one flight per day will find about 20 percent of the total passengers seeking the service. With two flights this grows to about 42 percent, and if 20 flights per day are offered, the demand increases to 98 percent. Note that for longer trips the frequency required to obtain 90% of the potential decreases.

The curves for Figure 7-A-3 are represented by the exponential function:

$$EFF = 1 - \exp\left[- (0.0542\, M^{0.41})\, F^{2M^{(-0.162)}}\right]$$

where: M ... Flight distance in miles for $100<M<1500$

F ... Flights per day

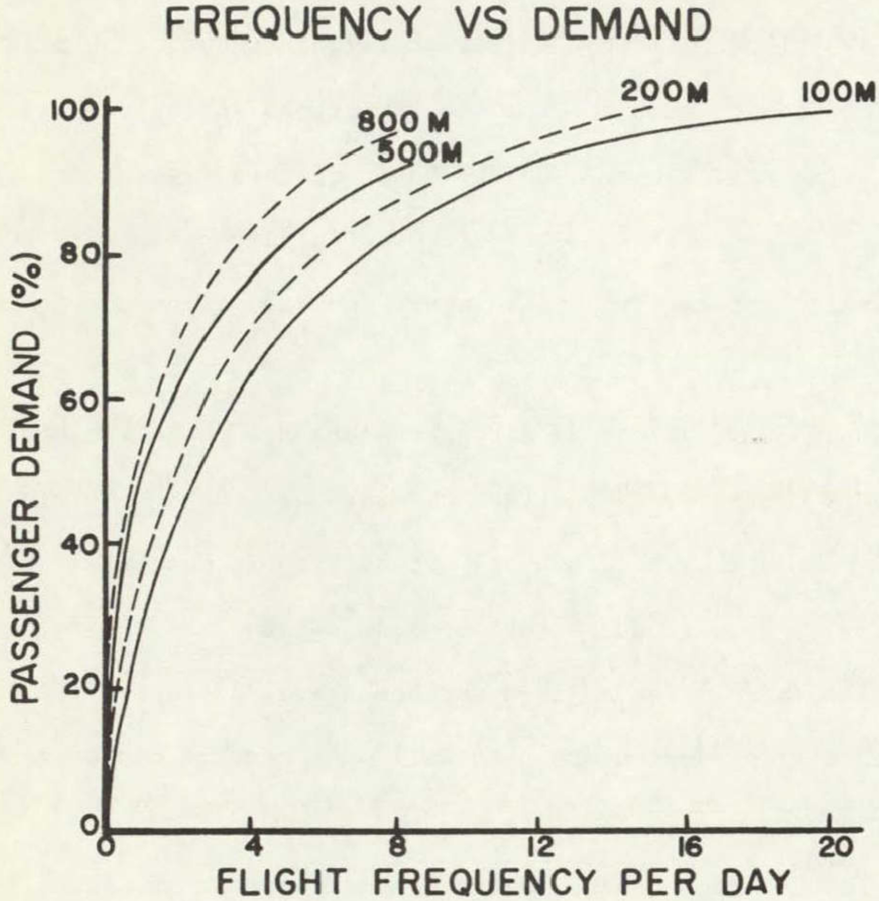


Figure 7-A-3

7-A-4 Ride Comfort [1]

Ride comfort is quantified by calculating the vertical g's (bounce) due to a unit gust loading. This is a function of an airplane's characteristics (for example: wing span, aspect ratio, weight, altitude, speed). The ride comfort elasticity is defined by the ratio of "percent change in RPM to percent change in ride comfort." This elasticity has the value of 0.15. That means one percent change in ride comfort implies 0.15 percent change in RPM.

7-A-5 Noise [1]

The overall sound level in the interior aircraft cabin is the average of the sum of the sound pressure levels of all frequencies between 600 and 4800 CPS and is measured in decibels per passenger-hour. The sound level elasticity is defined by the ratio of "percent change in RPM to percent change in the inverse of the sound level." This elasticity has the value of 0.15.

7-A-6 Safety [1]

Safety is quantified by taking the inverse of the number of accidents plus two times the passenger fatalities (accounting for large seat capacities of aircraft). The safety elasticity is defined by the ratio of "percent change in RPM to percent change in the inverse of the number of passenger fatalities." This elasticity has the value of 0.3.

7-A-7 Effectiveness Function

Time constraints on the project required the reduction of the final equation to the form:

$$TRPM = \sum_{\text{all } i} (PPM)_i \times (EFT)_i \times (EFF)_i$$

where: TRPM = Total Revenue Passenger Miles

i = ith route

PPM = Potential Passenger Miles

EFT = Effectiveness Function for Travel Time

EFF = Effectiveness Function for Flight Time

7-A-8 Computer Printout

The following is an actual computer printout of the Effectoveness Model written in the FORTRAN IV computer language.

```
      DIMENSION KDIST(11,11),              AFT(11,11), KFREQ(11,11),
     1  NSFIJ(11,11),NCFIJ(11,11), NSPE(11), NCPE(11),
     2  NCTAP(11),KSTOL(11,3,36),KCTOL(11,3,36),KGTST(11,2,36),
     3  KGTCT(11,2,36),NSP(11),NCP(11) ,EXTT(11,11)
     5, NPF(11,11,36)
  100 FORMAT(3X,11I4)
  101 FORMAT(I2,I2,11I6)
  102 FORMAT(20X,I2,I2,11I6)
  103 FORMAT(34H  AVERAGE FLYING TIME FROM I TO J  )
  104 FORMAT(I2,I2,11F6.3)
  105 FORMAT (20X,I2,I2,11F6.3)
  106 FORMAT(26H  FREQUENCY MATRIX I TO J      )
  107 FORMAT(23H  CONTROL INPUT RUN NO.       ,I4)
  108 FORMAT(I2,I4,6I5)
  109 FORMAT(20X,I2,I4,6I5)
  110 FORMAT(I2,I4,4I5)
  111 FORMAT(20X,I2,I4,4I5)
  112 FORMAT(29H  NUMBER STOL FLIGHTS I TO J    )
  113 FORMAT(24H  TERMINAL INPUT RUN NO.         ,I4)
  115 FORMAT(29H  NUMBER CTOL FLIGHTS I TO J    )
  116 FORMAT(I2,I2,22I3)
  117 FORMAT(20X,I2,I2,22(I3,1X))
  118 FORMAT(I2,I2,I10,I10,I3,I6)
  119 FORMAT(20X,I2,I2,I10,I10,I3,I6)
  120 FORMAT(36H  EXP STOL PAX, EXP CTOL PAX, APORT    )
  121 FORMAT(     I2,2I3,4X,I8,12X,I8,6X,I4)
  122 FORMAT(20X,I2,2I3,4X,I8,12X,I8,6X,I4)
  123 FORMAT(42H  NUMBER OF PEOPLE FLYING I TO J   RUN NO.  ,I4)
  124 FORMAT(27H1 ERROR IN BLOCK SEQUENCES    )
  125 FORMAT(22H1 ERROR INSIDE BLOCK    )
  126 FORMAT(2I2,11I4,2I10,I2,I5)
  127 FORMAT(20X,2I2,11I4,2I10,I2,I5)
  128 FORMAT(55H1 THIS IS THE OUTPUT FOR THE TERMINAL MODEL FOR RUN NO.,
     1I3)
  129 FORMAT(1H1)
  130 FORMAT(16H1 END OF RUN NO.  ,I3,19H  TOTAL REVENUE = $  ,F12.2,
     1  17H  EFFECTIVENESS =  ,I10)
      DO  5 I=1,11
      READ(5,100)(KDIST(I,J),J=1,11)
      DO 5 J=1,11
      D = KDIST(I,J)
      EXTT(I,J) = 50. + ( D /  400.0 ) * 60.0
    5 CONTINUE
      MIKE = 9
      N = 0
      NRUN = N
      RPM = 0.25
      DO 60 L=1,MIKE
      NRUN = NRUN + 1
      WRITE (6,107)NRUN
      DO 60 I=1,11
      READ(5,108) KID,(KSTOL(I,K1,L),K1=1,3),(KCTOL(I,K2,L),K2=1,3),J
      WRITE(6,109) KID,(KSTOL(I,K1,L),K1=1,3),(KCTOL(I,K2,L),K2=1,3),J
      IF (KID.NE.24) GO TO 90
      IF (J.NE.I) GO TO 95
   60 CONTINUE
      NRUN = N
      WRITE(6,129)
```

```
      DO 70 L=1,MIKE
      NRUN = NRUN + 1
      WRITE (6,113) NRUN
      DO 70 I=1,11
      READ(5,110) KID,(KGTST(I,K1,L),K1=1,2),(KGTCT(I,K2,L),K2=1,2),J
      WRITE(6,111)KID,(KGTST(I,K1,L),K1=1,2),(KGTCT(I,K2,L),K2=1,2),J
      IF (KID.NE.34) GO TO 90
      IF (J.NE.I) GO TO 95
   70 CONTINUE
      NRUN = N
      WRITE(6,129)
      DO 80 L=1,MIKE
      TR = 0
      WRITE(6,129)
      NRUN = NRUN + 1
      WRITE(6,123) NRUN
   10 DO 20 I=1,11
      READ(5,101)   KID,K,(NPF(I,J,L),J=1,11)
      WRITE(6,102)  KID,K,(NPF(I,J,L),J=1,11)
      IF (KID.NE.14) GO TO 90
      IF (K.NE.I) GO TO 95
   20 CONTINUE
      WRITE (6,103)
      DO 30 I=1,11
      READ (5,104) KID,K,(AFT(I,J),J=1,11)
      WRITE (6,105) KID,K,(AFT(I,J),J=1,11)
      IF (K.NE.I) GO TO 95
      IF (KID.NE.14) GO TO 90
   30 CONTINUE
      WRITE (6,106)
      DO 40 I=1,11
      READ(5,126)  KID,K,(KFREQ(I,J),J=1,11),NSPE(I),NCPE(I),NCTAP(I),
     1MSRL
      WRITE(6,127) KID,K,(KFREQ(I,J),J=1,11),NSPE(I),NCPE(I),NCTAP(I),
     1MSRL
      IF (KID.NE.14) GO TO 90
      IF (K.NE.I) GO TO 95
   40 CONTINUE
      WRITE (6,112)
      DO 45 I=1,11
      READ(5,116)  KID,K,(NSFIJ(I,J),J=1,11),(NCFIJ(I,K1),K1=1,11)
      WRITE(6,117) KID,K,(NSFIJ(I,J),J=1,11),(NCFIJ(I,K1),K1=1,11)
      IF (KID.NE.14) GO TO 90
      IF (K.NE.I) GO TO 95
   45 CONTINUE
      NPTOT = 0
      KID=47
      DO 79  I = 1,11
      NOPI = 0
      DO 75 J=1,11
      FS=NSFIJ(I,J)/(NSFIJ(I,J)+NCFIJ(I,J))
      FC=1.-FS
      CT=KGTCT(I,1,L)+KGTCT(I,2,L)+KCTOL(I,3,L)+KCTOL(I,1,L)+
     1KCTOL(J,2,L)+KCTOL(J,3,L)+KGTCT(J,1,L)+KGTCT(J,2,L)
      ST=KGTST(I,1,L)+KGTST(I,2,L)+KSTOL(I,3,L)+KSTOL(I,1,L)+
     1KSTOL(J,2,L)+KSTOL(J,3,L)+KGTST(J,1,L)+KGTST(J,2,L)
      AFT(I,J) = AFT(I,J) * 60.0
```

```
      TT=AFT(I,J)+ST*FS+CT*FC
      DIST=KDIST(I,J)
      FRQ =KFREQ(I,J)
      FACT1 = 1-EXP(-(0.0542*DIST**0.41)*FRQ**(2.0*DIST**(-0.612)))
      FACT2=(EXTT(I,J)/TT)**0.035
      AUX=NPF(I,J,L)
      TR = TR + RPM*DIST*AUX*FACT1*FACT2
      NPF(I,J,L)=AUX*FACT1*FACT2
      NOPI=NOPI+NPF(I,J,L)
      NPTOT = NPTOT + KDIST(I,J)*NPF(I,J,L)
   75 CONTINUE
      TOT = NCPE(I) + NSPE(I)
      FS1 = NSPE(I)
      FS2 = NCPE(I)
      FS3 = NOPI
      NSP(I) = FS3 * (FS1/TOT)
      NCP(I) = FS3 * (FS2/TOT)
      WRITE (6,122) KID,NCTAP(I),I,NSP(I),NCP(I),MSRL
   79 CONTINUE
      WRITE(6,130) L,TR,NPTOT
   80 CONTINUE
   90 WRITE (6,124)
      STOP
   95 WRITE(6,125)
      END
```

APPENDIX 7-A REFERENCES

[1] E. S. Quade and W. I. Boucher, Systems Analysis and Policy Planning Applications in Defense, Amer. Elsevier Pub. Co. Inc., New York, 1968.

[2] R. E. Corrigan and R. A. Kaufman, Why System Engineering, Fearon Publishers, Palo Alto, California, 1966.

[3] A. D. Hall, A Methodology for Systems Engineering, D. Van Nostiand Co. Inc., New York, 1962.